Rothamsted Experimental Station
Harpenden, Herts.

LAWES AGRICULTURAL TRUST

REPORT

for

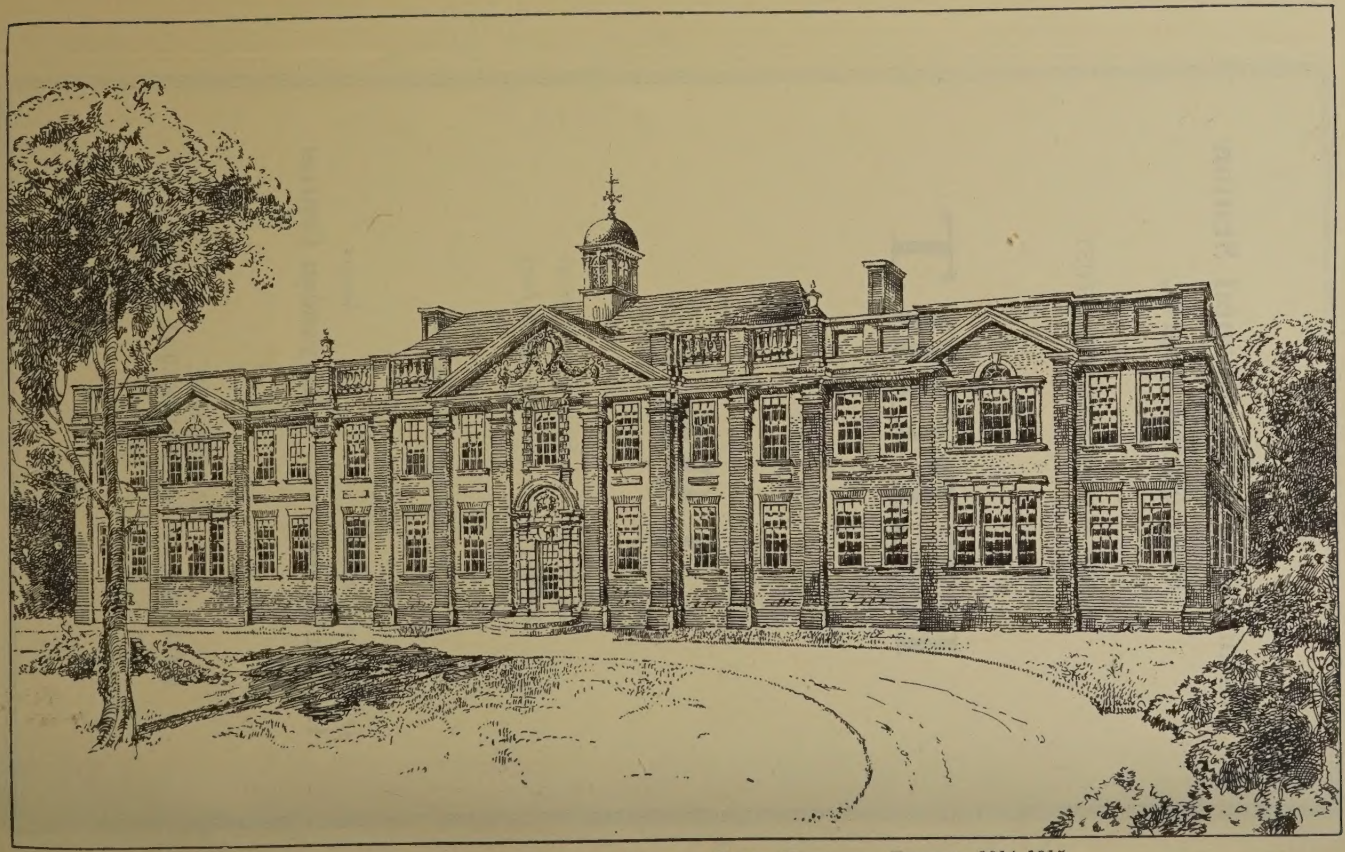
1961

To be obtained from the Librarian
Price Fifteen Shillings (Post free)

Telephone and Telegrams
Harpenden 4671

Station
Harpenden Central

HARPENDEN
ROTHAMSTED EXPERIMENTAL STATION
1962



The Rothamsted Laboratories for Soil and Plant Nutrition, Erected 1914–1915.

CONTENTS

The Lawes Agricultural Trust 5

The Incorporated Society for Extending the Rothamsted Experiments 5

Staff of the Rothamsted Experimental Station 6

Staff of the Soil Survey of England and Wales 18

Staff of the Woburn Experimental Station 19

Staff of Broom's Barn Experimental Station 19

The Commonwealth Bureau of Soils 20

Introduction 21

General Report 23

Departmental Reports 34
- Physics 34
- Chemistry 42
- Pedology 65
- Soil Microbiology 73
- Botany 81
- Biochemistry 95
- Plant Pathology 103
- Nematology 122
- Insecticides and Fungicides 130
- Entomology 145
- Bees 157
- Statistics 162
- Field Experiments 171
  - The Rothamsted Ley-Arable Rotation Experiment 173
  - The Field Plots Committee 180
- The Farms:
  - Rothamsted 184
  - Woburn 189
- Woburn Experimental Station 193
- Dunholme Field Station 198

Soil Survey of England and Wales 209

Special Reviews

- Microbiological Observations on the Classical Fields at Rothamsted 219
- Barnfield 227

Abstracts of Papers 248

Publications of the Rothamsted Experimental Station ... 290

Books by Present and Past Members of the Rothamsted Staff 292

Map of the Farm

NOTE: Temperatures are given in centigrade except where otherwise indicated.

The Lawes Agricultural Trust

Trustees

THE RIGHT HONOURABLE THE EARL OF RADNOR, K.G., K.C.V.O., LL.D.

THE MOST HONOURABLE THE MARQUESS OF SALISBURY, K.G., P.C., F.R.S.

SIR EDWARD J. SALISBURY, C.B.E., D.Sc., F.R.S.

Lawes Agricultural Trust Committee

THE RIGHT HONOURABLE THE EARL OF RADNOR, K.G., K.C.V.O., LL.D. (Chairman)

SIR LAWRENCE BRAGG, O.B.E., M.C., F.R.S.

DR. J. RAMSBOTTOM, O.B.E., M.A.

PROFESSOR A. ROBERTSON, F.R.S. (Treasurer)

DR. L. E. SUTTON, F.R.S.

LIEUT.-COL. R. B. VERDIN, O.B.E., T.D., D.L.

PROFESSOR V. B. WIGGLESWORTH, C.B.E., F.R.S.

PROFESSOR D. D. WOODS, F.R.S.

F. C. BAWDEN, Esq., M.A., F.R.S. (Secretary)

The Incorporated Society for Extending the Rothamsted Experiments in Agricultural Science

Council

THE MOST HONOURABLE THE MARQUESS OF EXETER, K.C.M.G., LL.D.

THE RIGHT HONOURABLE THE EARL OF PORTSMOUTH

and members of the Lawes Agricultural Trust Committee.

Rothamsted Experimental Station

LIST OF STAFF

DECEMBER 1961

Director: F. C. Bawden, M.A.(Cantab.), F.R.S.

Deputy Directors:

A. Muir, Ph.D.(Edin.)
F. Yates, Sc.D.(Cantab.), F.R.S.

Secretary: J. B. Bennett, F.C.A.

PHYSICS DEPARTMENT

Head of Department

H. L. Penman, M.Sc., Ph.D.(Dunelm), F.inst.P.

Scientific Staff

G. H. Cashen, M.Sc.(Manc.)
J. A. Currie, Ph.D.(Dunelm)
I. F. Long
J. L. Monteith, B.Sc.(Edin.), Ph.D.(Lond.), A.Inst.P.
D. A. Rose, B.Sc.(Lond.)
G. Szeicz, Dip.Met.(Budapest)

Temporary Workers

R. E. Shapiro, B.Sc.(C.C.N.Y.), Ph.D.(Ohio State)
C. E. Hounam, M.Sc.(Melbourne)

Assistant Staff

A. T. Day, B. K. French, W. C. Game, B.E.M., M. R. Richardson, Janet Taylerson, Jessie A. J. Walker

CHEMISTRY DEPARTMENT

Head of Department

G. W. Cooke, Ph.D.(Lond.), F.R.I.C.

Scientific Staff

P. W. Arnold, M.A.(Cantab.), B.Sc.(Wales), Ph.D.(Lond.), A.R.I.C.
Blanche Benzian, B.Sc.(Lond.)
Marie Blakemore, B.Sc.(Lond.)
Barbara M. Close, B.Sc.(Manc.), Dip.Hort.Sci.(Bristol)
R. K. Cunningham, B.Sc.(Edin.)
J. M. d'Arifat, B.Sc.(Wales)
M. St. J. Foale
J. K. R. Gasser, B.Sc.(Nott.), M.Sc.(Lond.), A.R.I.C.
Signe G. Heintze, M.Phil.(Stockholm)
D. S. Jenkinson, Ph.D.(Dublin)

A. E. Johnston, B.Sc.(Wales)
G. E. G. Mattingly, Ph.D.(Reading)
A. C. D. Newman, D.Phil.(Oxon.)
T. Z. Nowakowski, Ing.Agr.(Poznan), Ph.D.(Reading)
A. Penny, B.Sc.(Aberd.)
H. A. Smith
O. Talibudeen, M.Sc.(Lucknow), Ph.D.(Lond.)
R. G. Warren, B.Sc.(Lond.)
F. V. Widdowson, B.Sc.(Reading)
R. J. B. Williams, B.Sc.(Lond.)

Temporary Workers

A. Karim, M.Sc.(Dacca), Ph.D.(Adelaide)
Y. C. Lin, B.Sc.(Taiwan)
R. C. Salmon, B.Sc.(Cape Town), M.A.(Oxon.), A.R.I.C.
J. M. Walker, B.S.(Rutgers), Ph.D.(Purdue)

Assistant Staff

R. J. Avery, E. Bird, Mrs. Margaret A. Burn, J. J. Butler, Jeanette Chapman, Margaret Chater, Nellie Cressey, J. Day, R. C. Flint, S. C. R. Freeman, Mrs. Jean Goodchild, B. Harrison, Linda G. Hayes, M. V. Hewitt, R. D. Kerling, T. W. MacCormack, Brenda Messer, Mrs. Joyce W. Munden, D. E. Packer, Mrs. Katherine Penny, R. A. G. Rawson, M. Roberts, Mrs. Stella Roberts, Mrs. Gwendoline A. Rowsell, C. C. Rundle, P. B. Salisbury, F. J. Seabrook, B.E.M., R. Selby, Mrs. Yvonne Taylor, J. R. Wilkinson, D. F. Williams, Georgina L. Wood

PEDOLOGY DEPARTMENT

Head of Department

A. Muir, Ph.D.(Edin.)

Scientific Staff

C. Bloomfield, Ph.D.(Lond.), F.R.I.C.
G. Brown, B.Sc.(Glas.)
Sally Burnett, C.D.H.(Studley)
G. Dibley
R. Greene-Kelly, Ph.D.(Lond.)
G. Pruden
J. H. Rayner, D.Phil.(Oxon.)
I. Stephen, B.Sc.(St. And.), Ph.D.(Lond.)
A. H. Weir, Ph.D.(Lond.)

Temporary Worker

J. P. Watson, M.A.(Oxon.)

Assistant Staff

R. Farrow, R. C. Gallavan, Mrs. Constance M. Goble, Susan Heady, Dorothy Hester, J. J. Holton, R. Kanaris-Satiriou

TROPICAL SOILS ADVISER

H. Greene, D.Sc.(St. And.)
Secretary: Alice D. Stewart

SOIL MICROBIOLOGY DEPARTMENT

Head of Department

P. S. Nutman, Ph.D.(Lond.), A.R.C.S.

Scientific Staff

Margaret E. Brown, Ph.D.(Lond.)
Susan K. Burlingham, B.Sc.(Lond.)
R. Cooper, D.Phil.(Oxon.)
R. M. Jackson, Ph.D.(Lond.)
Mrs. Janina Kleczkowska, Ph.D.(Cracow), Ph.D.(Lond.)
Jane Meiklejohn, Ph.D.(St. And.)
F. A. Skinner, M.A.(Cantab.), Ph.D.(Lond.)
N. Walker, Ph.D.(Leeds), F.R.I.C.

Temporary Workers

J. F. Darbyshire, M.Sc.(Rhodes)
Barbara Mosse, Ph.D.(Lond.)

Assistant Staff

J. M. Brooks, Joan Crawley, Mabel Dunkley, Ruth M. Gooden, Mrs. Laveda Longbone, Eileen M. Macrow, Marion Sanders

BOTANY DEPARTMENT

Head of Department

D. J. Watson, Ph.D.(Cantab.)

Scientific Staff

S. A. W. French
P. J. Goodman, B.Sc.(Lond.), Ph.D.(S'ton.)
E. C. Humphries, D.Sc.(Lond.)
B. Orchard, B.Sc.(Sheffield), Ph.D.(Lond.)
Gillian N. Thorne, B.A.(Cantab.), Ph.D.(Lond.)
Joan M. Thurston, B.Sc.(Lond.)
P. J. Welbank, Ph.D.(Cantab.)
A. W. Wheeler, Ph.D.(Lond.)
K. J. Witts, B.Sc.(Wales), Ph.D.(Lond.)

Temporary Worker

G. J. Leach, B.Sc.(Reading)

Assistant Staff

Pamela B. Ash, J. J. Bentley, Audrey F. Evans, Lesley M. Freeman, Frances M. Halliday, Caryl M. Henry, A. R. C. Hill, M. G. Mathews, R. P. Moroney, Heather Pellant

BIOCHEMISTRY DEPARTMENT

Head of Department

N. W. Pirie, M.A.(Cantab.), F.R.S.

Scientific Staff

Marjorie Byers, B.Sc.(Bristol), A.R.I.C.
A. J. Clarke, B.Sc.(Glas.), Ph.D.(Lond.)
M. N. G. Davys
G. N. Festenstein, M.Sc.(S. Africa), Ph.D.(Liv.)
J. M. Hill, B.Sc.(Lond.)
Margaret Holden, B.Sc.(Lond.)
R. H. Kenten, B.Sc.(Lond.)
P. J. G. Mann, B.Sc.(Birm.), Ph.D.(Cantab.)
J. E. Morrison, B.Sc.(Aberd.)
W. S. Pierpoint, Ph.D.(Sheffield)
N. Singh, B.Sc.(Ag.), M.Sc.(Agra), Ph.D.(Lond.)
J. W. Sturrock, Ph.D.(Edin.), Dip.Agric.(Cantab.)

Temporary Worker

F. H. Shah, M.Sc.(Lahore)

Assistant Staff

H. Doyle, K. E. Fletcher, Mrs. Janet Gower, A. Johnston, Christine Poole, Jean Ward

PLANT PATHOLOGY DEPARTMENT

Head of Department

P. H. Gregory, D.Sc.(Lond.)

Scientific Staff

E. W. Buxton, Ph.D.(Cantab.)
Judith Cox, B.Sc.(Bristol)
Lina Cunow
A. J. Gibbs, Ph.D.(Lond.), A.R.C.S.
Mary D. Glynne, O.B.E., D.Sc.(Wales)
B. D. Harrison, B.Sc.(Reading), Ph.D.(Lond.)
G. D. Heathcote, Ph.D.(Lond.)
J. M. Hirst, D.S.C., B.Sc.(Reading), Ph.D.(Lond.)
B. Kassanis, D.Sc.(Lond.)
G. H. King, N.D.H.
A. Kleczkowski, M.D.(Cracow), Ph.D.(Lond.)
Mrs. Maureen E. Lacey
D. H. Lapwood, Ph.D.(Lond.), A.R.C.S., D.I.C.
I. Macfarlane, B.Sc.(Glas.), Ph.D.(Lond.)
H. L. Nixon, M.A.(Cantab.)
G. A. Salt, M.A.(Oxon.), Ph.D.(Lond.)
E. P. Serjeant, B.A.(Cantab.)
D. B. Slope
O. J. Stedman
Mrs. Marion A. Watson, Ph.D.(Liv.)
R. D. Woods

Temporary Workers

P. Babos, B.Sc.(Birm.)
R. C. Close, M.Sc.(New Zealand)
H. F. Dias, Eng.Agron.(Lisbon)
J. B. Kendrick, Ph.D.(Wisconsin)
O. Khalifa, B.Sc.(Agric.)(Khartoum)
J. Lacey, B.Sc.(Reading)
M. A. Ram Reddy, M.Sc.(Osmania)

Assistant Staff

Beatrice E. Allard, M. Bentley, Sheila E. L. Bunyan, Margaret Goodson, D. R. Henden, Judith Hillier, G. E. Hooper, Mary Jowett, J. A. Knight, Mrs. Elizabeth A. Lennon, Mrs. Nanette Lloyd, Mrs. Adriana Pflug, D. Roberts, Marie T. Seabrook, Maureen Thomson, Valerie Ward, B.Sc.(Lond.), A. A. Welch

NEMATOLOGY DEPARTMENT

Head of Department

F. G. W. Jones, M.A.(Cantab.)

Scientific Staff

C. C. Doncaster, B.Sc.(Wales)
Mary T. Franklin, D.Sc.(Lond.)
Margaret C. Gander, B.Sc.(Lond.)
J. B. Goodey, D.Sc.(Lond.)
D. N. Greet, B.Sc.(Lond.)
D. J. Hooper
J. E. Peachey, Ph.D.(Dunelm)
Audrey M. Shepherd, Ph.D.(Lond.)
H. R. Wallace, D.Sc.(Liv.)
J. M. Webster, B.Sc.(Lond.), A.R.C.S.

Temporary Workers

C. D. Blake, B.Sc.Agr.(Sydney)
K. K. Nirula, Ph.D.(Punjab)
G. N. Rao, M.A.(Madras)
G. Swarup, Ph.D.(Kansas)

Assistant Staff

Margaret R. Chapman, Mrs. Janet A. Cowland, Sybil A. Cox, Ann G. Joyce, Judith Killick, D. Lowe, Mrs. Valerie H. Meaton, Margaret M. Mulcahy, Ann M. Seabrook, Mrs. Molly Spears, D. Stanbridge, B. J. Wareham

INSECTICIDES AND FUNGICIDES DEPARTMENT

Head of Department

C. POTTER, D.Sc.(Lond.), D.I.C.

Scientific Staff

R. BARDNER, B.Sc.(Lond.)
P. E. BURT, B.A.(Cantab.)
M. ELLIOTT, PH.D.(Lond.)
P. ETHERIDGE, B.Sc.(Lond.)
MRS. EILEEN M. GILLHAM, B.Sc.(Lond.)
MRS. GERTRUD GREEN, B.Sc.(Lond.), A.R.C.S.
K. A. JEFFS
C. T. JEPHCOTT, N.D.H.
K. A. LORD, M.A. (Cantab.), PH.D.(Lond.), A.R.I.C.
A. H. MCINTOSH, B.Sc.(Edin.), PH.D.(Lond.)
FRANCES M. E. MOLLOY, PH.D.(Lond.)
P. H. NEEDHAM, B.Sc.(Manc.)
F. T. PHILLIPS, PH.D.(Lond.)
R. M. SAWICKI, PH.D.(Lond.)
S. R. B. SOLLY, B.Sc.(Lond.), A.R.I.C.
J. H. STEVENSON, PH.D.(Lond.), D.I.C., A.R.C.S.

Temporary Worker

A. A. BUADU

Assistant Staff

A. J. ARNOLD, BEATRICE A. BUNTING, D. E. EASTLAND, MRS. DOREEN FISHER, MRS. JENNIFER FOREST, AUDREY GATHERGOOD, R. E. GOODCHILD, VALERIE J. HASKING, K. E. HAWTON, CLARA SCHELWALD, B.Sc.(Lond.), MARIAN SMITH, ELOISE STONES, R. P. WEST

ENTOMOLOGY DEPARTMENT

Head of Department

C. G. JOHNSON, D.Sc.(Lond.)

Scientific Staff

MARGARET K. ARNOLD, B.Sc.(Sheffield)
C. J. BANKS, PH.D.(Lond.)
A. J. COCKBAIN, B.Sc.(Manc.), PH.D.(Lond.)
C. A. EDWARDS, M.Sc.(Bristol), PH.D.(Wisconsin)
R. A. FRENCH, B.Sc.(Lond.)
G. W. HEATH, B.Sc.(Dunelm), PH.D.(Lond.)
T. LEWIS, B.Sc.(Nott.), PH.D.(Lond.), M.A.(Cantab.)
J. R. LOFTY
D. S. MADGE, B.Sc.(Sheffield), PH.D.(Lond.)
F. RAW, PH.D.(Lond.)
J. W. STEPHENSON, M.Sc.(Lond.)
L. R. TAYLOR, B.Sc.(Lond.)

Temporary Workers

G. K. A. Buahin, B.Sc.(Lond.)
D. Calnaido, B.Sc.(Ceylon)
Imam El Khidir, B.Sc.(Cairo), M.Sc.(Khartoum)
R. MacGregor-Loaeza
Frances M. Smith, B.A.(Cantab.)
W. S. Tallack, B.Sc.(Sheffield)

Assistant Staff

Christine V. Bell, T. H. Bingham, D. C. Bowler, Janet K. Davie, Dorothy J. Davies, Maureen Dupuch, H. H. Franklin, Anne Hemmings, Valerie McKinney, R. E. Pflug, Barbara J. Pyrah, Rosemary J. Webb, A. E. Whiting

BEE DEPARTMENT

Head of Department

C. G. Butler, Ph.D.(Cantab.)

Scientific Staff

L. Bailey, M.A.(Cantab.), Ph.D.(Lond.)
Elaine M. Fairey, B.Sc.(Lond.)
J. B. Free, M.A.(Cantab.), Ph.D.(Lond.)
D. C. Lee, B.Sc.(Bristol)
Inge B. M. Riedel, B.Sc.(Lond.)
J. Simpson, M.A.(Cantab.), Ph.D.(Lond.)
H. Yvette Spencer-Booth, B.A.(Cantab.), B.Sc.(South Africa)

Temporary Worker

J. P. Spradbery, B.Sc.(Lond.)

Assistant Staff

D. V. Alford, N. E. Ellement, Patricia A. Garrett, A. R. W. Griffin, N.D.B., C. W. B. Mares, Elizabeth M. Robinson, C. M. Smith, W. A. Stevens, P. W. Tomkins, R. A. Welch

STATISTICS DEPARTMENT

Head of Department

F. Yates, Sc.D.(Cantab.), F.R.S.

Scientific Staff

G. W. Bonsall, B.A.(Oxon.)
B. M. Church, B.Sc.(Lond.)
D. A. Boyd, Ph.D.(Lond.)
A. G. Davies
J. R. Davis, M.A.(Oxon.)
J. H. A. Dunwoody, B.A.(Oxon.)
C. W. Fearne
A. Frater, B.Sc.(Edin.)

J. C. Gower, M.A.(Cantab.)
M. J. R. Healy, B.A.(Cantab.)
M. L. Hill
Mary G. Hills, B.A.(Cantab.)
P. Holgate, B.Sc.(Exe.)
F. B. Leech, D.Sc.(Belfast), B.Agr.(Belfast), M.R.C.V.S.
W. J. Lessells, B.Sc.(Nott.)
A. H. Martin, B.Sc.(Lond.)
Mrs. Marjory G. Morris, Ph.D.(St. And.)
H. D. Patterson, M.Sc.(Leeds)
D. H. Rees, B.Sc.(Lond.)
G. J. S. Ross, B.A.(Cantab.)
Mrs. Emily P. Simpson, B.A.(Oxon.)
H. R. Simpson, M.A.(Cantab.)
A. J. Vernon, B.Sc.(Reading)
M. P. Vessey, M.B., B.S.(Lond.)

Temporary Worker

C. A. Hoveyn

Assistant Staff

Ruth T. Hunt (Secretary)
Margaret C. Adams, Mrs. Betty E. Artiss, Mrs. Marian G. Ascott, Mrs. Josephine M. Bonsall, Dorothy C. Clark, Mrs. Doris A. Court, Mrs. Elsie Davies, Mrs. Doreen Edwards, Jane L. Gardner, Mrs. Beryl C. Hood, Jennifer M. Horth, Constance Hunt, Mrs. Ethel J. Jenkins, Mrs. Joyce McKeown, Lucille V. Legg, Mary J. Maguire, Mrs. Ena N. Nicholls, Mrs. Sheila O'Reilly, Mrs. Dorothy G. Palk, Mrs. Verona A. Roberts, Jennifer M. Saunders, Olive Sparkes, Mrs. Anne Vessey, Mrs. Freda A. Walker, Mrs. Margaret P. Whittingham

FIELD EXPERIMENTS SECTION

Head of Section

G. V. Dyke, M.A.(Oxon.)

Staff

H. V. Garner, O.B.E., M.A.(Cantab.), B.Sc.(Liv.)
J. McEwen, B.Sc.(Birm.), Dip.Ag.Sci.(Cantab.), D.T.A. (Trin.)
M. J. Allen
G. F. Jarvis, M.Sc.(Dunelm)
C. R. L. Scowen
Myrtle Hughes (Clerical Assistant)

STAFF OF FARMS

Head of Farms

J. R. Moffatt, B.Sc.(Lond.), N.D.A.

Deputy Farm Manager

R. Moffitt, B.Sc.(Reading)

Assistant Farm Manager
G. F. Cole

Secretary
Brenda Simpson

Chief Recorder
J. M. Bidgood

Recorders
F. V. Cooper, Dip.Agric.(Wye)
A. S. Koster
D. Martin

Bailiff (Woburn)
A. W. Neill

Foreman (Rothamsted)
W. A. H. Burton

Farm Workers
T. Ablewhite, J. Alexander, T. Battams, J. Bird, V. Bowes, T. Card, H. S. Chapman, P. W. Currant, C. Hathaway, A. Jennings, A. W. Livingstone, E. McMillan, H. Millard, T. F. Nibloe, K. Smith, C. E. Wagstaff, C. Welbourne, W. Wilson

LIBRARY

Librarian
D. H. Boalch, M.A.(Cantab.)

Assistant Librarian
Mrs. Geraldine Lawrence

Assistants
Sylvia Mann, Mary L. Nash, A.L.A.

ADMINISTRATIVE AND CLERICAL STAFF

Director's Personal Assistant
Mildred E. Ashford

Assistant Secretary
E. Church, A.A.C.C.A.

Cashier
Mrs. Olive Coleman

Clerical Staff
Jacqueline F. Bates, Mrs. Alice Baxter, Mrs. Yvonne Bird, Mrs. Pamela Blanking, Mrs. Mary K. Boutwood, Mrs. Dorothy Coates, Jennifer Lawrence, Mrs. Doris Price, Christine Shew

Storekeepers
F. W. Ellingham, B. R. Ledger

PHOTOGRAPHY

Photographer

V. Stansfield, F.R.P.S.

Assistants

F. D. Cowland, A.I.B.P., A.R.P.S.
Shirley M. Thomas

Draughtswoman

Mrs. Rosemary Nye-Browne

HALL OF RESIDENCE AND CANTEEN

Warden and Housekeeper

Audrey H. Benzie

Assistant Housekeeper

Mrs. Lola Kajtar

Staff

Maria G. Candal, Mrs. Rosina V. Fisher, C. W. Fisher, Mrs. Marjorie Hammond, Mrs. Elsie Lee, Mrs. Constance W. Mowbray, Mrs. Francis M. Rumbelow, Mrs. Doris Tilley

WORKSHOP AND MAINTENANCE STAFF

Head of Workshop and Maintenance Staff

A. E. Hall

Staff

W. L. Abbiss, W. G. Abbott, A. S. Bell, G. Berneye, C. F. Berry, L. C. Berry, T. J. Bishop, E. J. Burgess, D. J. Burn, E. W. Davis, B. S. Edwards, S. Foster, L. F. Fowler, E. Olley, R. C. Parrott, A. W. Primett, D. G. Tyler

Cleaners, etc.

Mrs. E. Bygrave, P. C. Carter, H. P. Currant, H. J. Ellen, Mrs. Violet Ellen, W. Haigh, Mrs. Florence Hamilton, W. F. Hewitt, F. T. Kidman, C. E. O'Dell, J. Rainbow, P. Rolt, F. J. Stock, H. A. Weston

Gardeners

W. Biggs, H. Goodenough, F. Hamilton, G. F. Hanson, K. Huntington, F. Ivory, F. E. Peacock

Members of the Scientific Staff who left between January and December 1961

Dunholme Field Station

S. N. Adams, D.Phil.(Oxon.)

Entomology

K. Mellanby, C.B.E., Sc.D.(Cantab.)

Farm

M. J. Hill, B.Sc.(Lond.)

Insecticides

Mrs. Evelyn M. Piall, B.Sc.(Lond.)
F. T. Last, Ph.D.(Lond.), D.I.C., A.R.C.S.

Nematology

R. D. Winslow, B.Agr.(Belfast), Ph.D.(Cantab.)

Soil Survey

E. M. Bridges, M.Sc.(Sheffield)
T. R. Paton, B.Sc.(Dunelm)

Statistics

D. J. Knight
Beryl Turner, B.Sc.(Lond.)

The following spent varying periods as temporary workers at Rothamsted during 1961:

Australia: N. J. Barrow (Chemistry), J. P. Riches (Botany), E. V. Robinson (Pedology), C. B. Wells (Pedology); **Belgium:** O. J. van Laere (Bee); **Canada:** Elizabeth J. Dimelow (Entomology), S. C. Jay (Bee), M. V. Smith (Bee); **Eire:** D. Harrington (Statistics), J. F. Moore (Nematology); **Germany:** D. Claus (Soil Microbiology); **Holland:** Jeanne Dykstra (Plant Pathology), P. Gaastra (Physics); **India:** S. N. Banerjee (Entomology and Nematology), P. M. Sankaran (Biochemistry), L. V. Vaidyanathan (Chemistry); **Indonesia:** Khouw-Foet Tjem (Biochemistry); **Italy:** Anna Marinari (Nematology), L. Verrini (Chemistry); **Jamaica:** O. G. de Lisser (Statistics); **Japan:** R. Kisimoto (Plant Pathology), K. Yabuki (Physics), Y. Yamada (Chemistry); **Kenya:** Meriol E. Fitzpatrick (Botany); **Malaya:** J. Lamin (Botany), Gloria Lim (Soil Microbiology); **New Zealand:** W. C. Clark (Nematology); **Nigeria:** S. I. Agwu (Entomology); **Norway:** O. Nissen (Statistics); **Pakistan:** M. Hussain (Biochemistry); **Persia:** A. Omidvar (Nematology); **Poland:** Kristine Pawelska (Nematology), A. Wilski (Nematology); **Portugal:** A. J. R. Lapa (Pedology); **Sierra Leone:** R. Q. Craufurd (Botany); **Spain:** H. G. Contreras (Physics), S. Oliver (Chemistry), M. Covadonga Rodrigues Pascual (Pedology), J. Rey (Insecticides); **Sudan:** I. A. Babiker (Pedology), A. R. A. Taha (Botany); **Sweden:** K. E. Lindsten (Plant Pathology); **Switzerland:** A. Graf (Nematology); **Uganda:** S. G. Kibirige (Soil Microbiology),

D. Mpairwe (Soil Microbiology); **Yugoslavia:** P. Atanasov (Nematology), Mrs. Branka Savic (Chemistry), K. Tarman (Entomology); **British Isles:** C. J. Andrews (Plant Pathology), M. G. Bell (Plant Pathology), Evelyn R. Bennett (Bee), Rosemary E. Boyd (Botany), Rosemary Fiddick (Plant Pathology), F. W. Flitney (Entomology), J. F. R. Gower (Chemistry), C. M. Graham (Field Experiments), Rachel Gregory (Plant Pathology), M. C. Grieve (Insecticides), Stella M. Hamm (Soil Microbiology), Virginia Hofton (Chemistry), Frances M. Jones (Plant Pathology), J. M. Laurent (Plant Pathology), A. H. Lloyd-Lawrence (Chemistry), D. Malithano (Plant Pathology), Margaret E. Richardson (Entomology), Patricia M. Ridout (Plant Pathology), E. Roberts (Bee), F. J. Sage (Botany), Astri W. Stanworth (Botany), J. H. Stevenson (Insecticides), W. D. Thomas (Botany), J. R. Tighe (Chemistry), J. Tunstall (Entomology), W. B. Wallace (Physics), Caroline A. Warne (Entomology), Helen V. M. Watson (Entomology), Barbara G. Williams (Nematology).

SOIL SURVEY OF ENGLAND AND WALES

Head of Survey

A. Muir, Ph.D.(Edin.)

Deputy Head of Survey

D. A. Osmond, Ph.D.(Bristol), A.R.I.C.

Soil Surveyors

G. D. Ashley, B.Sc.(Sheffield)
B. W. Avery, B.Sc.(Reading)
P. Bullock, B.A.(Birm.)
C. P. Burnham, B.A.(Cantab.), B.Sc.(Lond.)
B. Clayden, B.Sc.(Sheffield)
W. M. Corbett, B.Sc.(Edin.)
C. B. Crampton, Ph.D.(Bristol)
A. Crompton, B.Sc.(Leeds)
D. C. Findlay, M.A., Dip.Ag.Sci.(Cantab.)
C. J. Folland, B.Sc.(Bristol)
R. D. Green, M.Sc.(Lond.)
B. R. Hall, B.Sc.(Edin.)
C. A. H. Hodge, B.Sc.(Wales)
J. M. Hodgson, B.Sc.(Lond.)
M. G. Jarvis, B.A.(Oxon.)
R. A. Jarvis, B.Sc.(Dunelm)
D. W. King, B.Sc.(Lond.), A.R.I.C.
D. Mackney, B.Sc.(Bristol)
D. J. R. Manley, B.Sc.(Exe.)
C. C. Rudeforth, B.Sc.(Lond.)
R. S. Seale, M.A.(Cantab.)
G. R. Suggett, B.A. (Leeds)
A. J. Thomasson, B.A.(Bristol)

Colonial Pool of Soil Surveyors

A. O. Ballantyne, Ph.D.(Edin.)
P. D. Jungerius, Ph.D.(Amsterdam)
A. R. Stobbs, M.A.(Dunelm)

Chemists

C. L. Bascomb, B.Sc.(Reading)
Audrey M. Du Feu, B.Sc.(Lond.)
H. H. Le Riche, Ph.D.(Lond.)
D. T. Pritchard

Temporary Worker

Ismail Tunckale

Assistant Staff

R. Ball, Jean Burke, Mrs. Joan K. Foster, Mrs. Cynthia M. Gosney, P. G. Hoare, F. Johnson, Margaret Roe, Mrs. Pauline Sutcliffe, E. M. Thomson, A. V. Vann, C. V. Waine, M. J. Williamson

Woburn Experimental Station

(Husborne Crawley, Bletchley, Bucks.)

Officer in Charge

C. A. THOROLD, M.A.(Oxon.), A.I.C.T.A.

Chemist

T. W. BARNES, M.Sc.(Lond.), F.R.I.C.

Assistant Staff

G. PEARCE, Q. D. POPE

Broom's Barn Experimental Station

(Higham, Bury St. Edmunds, Suffolk)

Head of Station

R. HULL, PH.D.(Lond.)

Scientific Staff

W. J. BYFORD, B.Sc.(Lond.)
R. A. DUNNING, M.Sc.(Leeds), PH.D.(Cantab.)
M. GLENISTER, B.Sc.(Bristol)
P. J. LAST
G. H. WINDER, B.Sc.(Manc.)

Assistant Staff

C. J. HINGSTON, D. G. HODGSON, JANET HULL, J. IWANICKI, MRS. JOAN IWANICKA, J. A. P. MARSH, W. N. MOORE, MARIE D. WOLFE

The Commonwealth Bureau of Soils

Director	G. V. Jacks, M.A.
Consultant Director ...	F. C. Bawden, M.A., F.R.S.
Assistant Director ...	W. D. Brind, B.Sc.
Scientific Information Officers	G. A. Greenwood, B.Sc. Elizabeth E. Hardman, B.Sc. Mrs. M. Kathleen Milne, B.Sc. I. Szladits, Ph.D. Norah J. Watts, M.A.
Indexer	Mrs. Sophie Adams
Clerks	Mrs. Eileen G. Clark, Patricia A. Francis, Marguerita D. Payne, Mrs. Shirley Shorland

INTRODUCTION

Sir John Bennet Lawes was experimenting before 1843, but the Rothamsted Experimental Station dates its foundation from this year because he then started his long and fruitful collaboration with J. H. Gilbert and laid down the classical wheat experiment on Broadbalk field. Lawes died in 1900 and Gilbert in 1901: they were succeeded as directors by A. D. Hall (1902–12), E. J. Russell (1912–43), W. G. Ogg (1943–58) and F. C. Bawden (1958–).

Until 1904, when the Society for Extending the Rothamsted Experiments was instituted, the work was paid for wholly by Lawes, at first directly and from 1889 from the fund of £100,000 with which he endowed the Lawes Agricultural Trust. In 1906 Mr. J. F. Mason paid for a bacteriological laboratory to be built, and in 1907 the Goldsmith's Company provided an endowment of £10,000. The first public money came in 1911 from the Development Commission, and since then government grants have been made annually; now the work is largely financed by annual grants from the Agricultural Research Council.

For long the experimental fields amounted to only about 50 acres, which were worked from the Rothamsted Home Farm, but in 1913 this farm of 250 acres was rented by the Station and the first farm buildings were put up on the site of the present range. In 1934 the Manor House, Home Farm, the site of the laboratories and various other parts of the estate, were bought by the Lawes Agricultural Trust for £35,000, raised entirely from voluntary subscriptions. Since then some additional land and other houses have been acquired, and the total area now owned is 580 acres, of which about 300 are suitable for field experiments. In 1952 the Manor House was opened as a hostel for members of staff and visitors.

Research work at Crawley Mill Farm, Woburn, was started by the Royal Agricultural Society of England in 1876. Lawes and Gilbert were consulted about the experiments from the start, and some experiments done on the heavy land at Harpenden were duplicated there. After the Royal Agricultural Society withdrew its support from Woburn in 1921, the experiments there were supervised from Rothamsted and, in 1926, with the transfer of the lease to the Lawes Agricultural Trust Committee, Woburn Experimental Station formally became a part of Rothamsted. In addition to providing a valuable contrast of soil type, the land at Woburn allows experiments with crops not easily grown at Harpenden.

There is still need to do experiments at many other places, however, for different as these two farms are, they are far from representing all the major types of soils and climates in Britain. More than any other crop, sugar beet has been studied at other places in south and east England in work financed from the Sugar Beet Research and Education Fund, for which the Lawes Trust Committee has become increasingly responsible. From the 1930s the manuring of sugar beet was studied from Rothamsted, and to

this was added in 1947 work on the diseases, which during the 1950's was done mainly from the Dunholme Field Station, Lincoln. This was closed in 1961 and work transferred to the new Broom's Barn Experimental Station, Higham, Bury St. Edmunds, Suffolk, where, with new laboratories and glasshouses, and 200 acres of land, all problems of sugar-beet growing are now studied.

Although a range of problems was studied before 1900, the work was mostly chemical, and only few workers were engaged. With increasing numbers of staff in the early 1900s, the activities also widened and Departments of Botany, Soil Microbiology and Physics separated from the original Chemistry Department before 1914, and soon after the end of the First World War new Departments of Entomology, Plant Pathology, Insecticides and Fungicides, and Statistics were started. Except for additional posts for work on bees and on viruses and virus diseases, the Station's activities then expanded little until the Second World War, when most Departments increased in size and others were added for Pedology (1945), Biochemistry (1947) and Nematology (1947). In 1946 Rothamsted also became the headquarters of the Soil Survey for England and Wales. From a total of 28 in 1912, the staff increased to 140 in 1943 and 471 in 1958. The Commonwealth Bureau of Soils, one of the ten bureaux that act as clearing centres for information on agricultural science, has been housed here since its establishment in 1929. The Station also accommodates visiting workers, many of whom use the special relationship with London University to register as internal students of the university for research degrees.

The building of laboratories, glasshouses and other ancillaries has roughly paralleled the growth of staff, but has always lagged behind, so that at least some of the departments are always overcrowded, and the number of visiting workers that can be accepted is always much smaller than the number of applicants. Of the existing laboratories, the main block is the oldest and was opened in 1919; the North Building dates from 1924, the South Wing from 1940, the Nematology Building from 1947 and the West Building from 1955.

The Library

Until 1913, when Sir Henry Gilbert's books were given to the Station by his widow, the Library consisted almost entirely of Sir John Lawes's collection. It then grew rapidly in size and scope, until in 1917 it contained 10,000 volumes and in 1958 about 60,000 volumes. Its stock includes about 3,500 agricultural books published between 1471 and 1840, of which 13 are incunabula; 5,000 serial publications—1,700 of them current; 100 MSS. from the 13th century onwards, in addition to the Lawes and Gilbert papers; about 300 maps; and nearly 1,000 prints of livestock, mainly of the 18th and 19th centuries.

The following catalogues have been published: of serial publications (1954), of early agricultural books (1926, second edition 1940, supplement 1949) and of livestock prints (1958).

GENERAL REPORT

F. C. Bawden

H. H. Mann died on 2 December, a few weeks after his 89th birthday. He officially retired from the post of Assistant Director at Woburn in 1956, but he was active in our affairs until his death. With his interests undiminished and his faculties undimmed, he remained a member of the Staff Council and Field Plots Committee, and to their meetings as to our regular scientific meetings at Rothamsted he remained a valued and forthright contributor. His productive working life was as remarkable for its range and diversity as for its duration. He published his first paper, which described effects of antiseptics on yeast, in 1897, and he was writing one at the time of his death on the Woburn Market-garden Experiment. In the 64 years between he worked twice at Woburn, and had what is normally regarded as a full career in India, where he held such posts as Scientific Officer to the Tea Association, Principal of the Poona Agricultural College and Director of Agriculture for Bombay State. His work there not only established him as a world's authority on the tea crop but made him the most respected and influential person in Indian agricultural science. His first stay at Woburn was relatively brief, from 1898 to 1900, while he worked as assistant to Dr. J. A. Voelcker, Chemist to the Royal Agricultural Society of England, which was then responsible for Woburn. However, the stay gave him a lasting interest in the station and the district, and he returned there in 1928 after retiring from India. Until 1936 he was in charge of the experiments at Woburn, the lease of which had passed from the Royal Agricultural Society to Dr. Voelcker in 1921 and from him to the Lawes Agricultural Trust Committee in 1926, but from 1936 to 1946 Mann also shouldered the responsibility for running the whole farm. There is no need here to list the many subjects he successfully studied, for he summarised the work at Woburn in the Report for 1958. That article not only shows the range of his interests but the enthusiasm and activity with which he pursued them; it must be unique as an account of research achievements by someone in years far beyond any official retiring age. Even so, there was more to his life than agricultural research and, in both India and Bedfordshire, he was active in local affairs and tireless in his work to improve social conditions.

Membership of Trust Committee

Lt.-Col. R. B. Verdin was appointed to the Lawes Agricultural Trust Committee by the Royal Agricultural Society of England to replace Mr. A. H. Carter, who resigned.

Head of Entomology Department

C. G. Johnson was appointed head of the Entomology Department to succeed K. Mellanby, who left on 30 September to become

director of a new research station of the Nature Conservancy in Huntingdonshire.

Awards

F. J. Seabrook's services were acknowledged in the Birthday Honours List by the award of the British Empire Medal. R. Hull was awarded the Research Medal of the Royal Agricultural Society of England in recognition of his work on sugar-beet diseases, particularly his success in checking yellows. The high quality of research done by B. Kassanis and A. Kleczkowski gained them promotion on merit to the grade of Senior Principal Scientific Officer. F. C. Bawden was elected to Foreign Membership of the Royal Netherlands Academy of Sciences and Letters. On the occasion of the bicentenary of the French Academy of Agriculture, the French Minister of Agriculture conferred on Sir John Russell the honour of Commander of the Order of Agricultural Merit.

In June we celebrated what will probably remain a unique occasion, when three members of staff, H. Currant, W. C. Game and F. J. Seabrook, reached almost simultaneously 50 years of continuous employment with the Lawes Agricultural Trust Committee. Regrettably Sir John Russell, who appointed them, could not attend the celebration in their honour; this was not for reasons that might have been expected for one in his 89th year, but because he had a long-standing engagement that day to inspect improved grassland on the mountain of Plynlimon.

Buildings

Some progress can be reported towards relieving our overcrowding. The new building in Rivers Lodge garden for the statisticians was finished and occupied, except for the room designed to house the Orion computer when it comes. A small extension to Red Gables to increase accommodation for the Soil Bureau was almost finished. The old Imperial College Laboratory was refurbished and occupied by members of the Botany Department, whose move freed some rooms for the library staff, who for years have had to work on the landing or in the library itself. At the end of the year builders were on the site and had dug an impressive hole where the considerable extension to the West Building should be completed by January 1963.

The largest developments were at Broom's Barn, where, despite the appalling mud during the winter, the roads, services and farm buildings were all completed in June. By the end of 1961 the six houses were finished and three occupied; most of the laboratory and other buildings also had their roofs on. After deepening the first borehole, enough water was obtained to irrigate 2 acres at a time. The staff still at Dunholme will move to Broom's Barn in the spring, and Dunholme Field Station will close.

Visits and visitors

Many members of the staff again travelled overseas not only, or even mainly, to attend scientific congresses but as the result of invitations to lecture, to advise or to undertake specific research

problems. In addition to travels recorded by the individual departments, F. C. Bawden visited the Sudan in January to attend a meeting of the Agricultural Advisory Committee, the U.S.A. in April to lecture at the University of California, Kenya in October to represent the Secretary of State for the Colonies at a meeting of the East African High Commission and Ceylon in December to visit the Tea Research Institute.

Visitors to Rothamsted were fewer than in 1960, but we again recorded more than 3,000. Those from overseas included delegates from the Chinese Academy of Science, H.E. Dr. Esfandiar Esfandiari, Under-Secretary of State, Iran, and Mr. Sebalu, Minister for Economic Development, Uganda. Those from the United Kingdom included Mr. Denzil Freeth, M.P., Parliamentary Secretary to the Minister for Science.

The year and farming

The year began with farm work so far behind schedule that there seemed little hope of ever catching up. However, Broadbalk was drilled on 18 January and, although the crop looked poor up to May, the yield at harvest was up to average. A dry spell in February allowed a further 20 acres to be sown with winter wheat, the potatoes to be lifted (unharmed by frost in the mild winter), and much land to be ploughed. The seed beds looked far from good, but the wheat seemed not to mind and when heavily manured yielded more than 50 cwt./acre. The unusual circumstances were used to compare winter and spring wheats sown on 15 February: Cappelle gave a mean yield of 45·8 cwt./acre and Jufy 1 43·3, so it was still worth sowing winter wheat even at this late date. The later-sown spring wheat and barley also went into rough seedbeds, and the crops looked uneven in May, but later improved, and the wheat averaged more than 40 cwt. and the barley about 40 cwt./acre. On the heavy Rothamsted land it is rare to be able to show effects of tilth or soil structure on crop yields, but this was achieved with spring beans by deliberately maltreating the seedbed. Plots, formerly in ley or fallow, were split into halves, one of which was disc harrowed when very wet and the other cultivated to get the best seedbed. Yields were 20% higher on the ley plot cultivated well than on the ley plot cultivated badly or the fallow plot cultivated well, and these yielded 20% more than the fallow plot cultivated badly.

On the lighter land at Broom's Barn tilth is more important; spring wheat and barley were particularly poor on land compacted and puddled by harvesting beet during the wet autumn, and yields averaged only 20 cwt./acre. At Woburn yields averaged 26 cwt./acre. Brown foot-rot (caused by *Fusarium* spp.) was prevalent in wheat at Woburn, and on other light land with poor structure, particularly where given large dressings of nitrogenous fertilisers.

How much the yields of cereals were affected by the virus disease barley yellow dwarf is unknown, but it was very common and must have damaged some of the late-sown spring cereals considerably. Another virus disease, motley dwarf of carrots, was so prevalent and damaging that it ruined most carrot crops sown during April and May in the south and east of England. Sugar-beet yellows, too,

appeared early and threatened to be severe for the fifth year in succession. Spray warnings went out in some areas during the second week of May, and by the end of June they had gone out almost everywhere, and some areas had been advised to repeat the spraying. More than three-quarters of the total beet acreage was sprayed, and those who sprayed when they were warned increased yields by enough to repay many times the cost of spraying. Unfortunately, not everyone did, for there were few black aphids on the crops, and it is these farmers notice, rather than the green ones that are mainly responsible for spreading yellows. Those who delayed suffered needless loss, but even so the total yield of beet for the country was the second highest ever recorded. The prevalence of virus diseases in recent springs probably reflects the succession of mild winters; infected plants and aphids that would be killed by a protracted frost have survived, and warm dry days in spring have favoured the early movement and multiplication of the aphids. It is to be hoped that the cold spell at the end of 1961 broke the succession of years favouring aphid-borne viruses, but although intense, it was only brief.

Like sugar beet, potatoes yielded well, though they went into rough ground and grew slowly at first. Some areas of early varieties at Woburn never recovered from the effects of frost on 27 May, but the maincrop varieties later made good growth and were unaffected by blight (*Phytophthora infestans*) until the second half of September. Further evidence for our earlier conclusion that the fungus can spread below ground was provided by the unique event that the first record of the fungus was in a new tuber; this happened early in August when sampling a King Edward crop in which lesions could not be found above ground. Copper sprays are often said to decrease potato yields in blight-free years, but yields from sprayed and unsprayed plots killed with acid in mid-September did not differ significantly. Sprayed plots left to mature naturally yielded nearly a ton per acre more than unsprayed plots, but with the susceptible variety King Edward this gain was largely illusory: leaving the tops to mature multiplied the weight of blighted tubers twentyfold, and this loss more than offset the extra weight put on. Hence, even in this year when blight was generally thought to be unimportant, losses of tubers could be large unless the haulms were killed at a critical time.

The yield of early potatoes at Woburn was more than doubled by irrigation equivalent to 4 inches of rain, which at the higher dressing of nitrogen increased yields by 8 tons of tubers/acre. Attempts to replace traditional cultivations by weedkillers of the triazine type were not a success.

Except for one week in June and one in July, the summer was dry to the beginning of August, and the other crops tested all responded well to irrigation; the yields of grass and spring beans were more than doubled and of barley increased by about 7 cwt./acre. Grass responded little to fertilisers unless it was irrigated. August brought 18 rainy days, which delayed the cereal harvest, and most grain had to be dried, but this harvest ended early in September, after which conditions favoured the root harvest and farm work in general. The year ended very differently from 1960; not only all crops harvested, most land ploughed and winter wheat and beans all

sown, but with 20° of frost on 29 December and 14 inches of snow on 31 December.

The ley-arable experiment

The practice of ley farming, or of taking the plough around the farm, has had many powerful advocates, and receives official blessing in the grants given to farmers who plough up pasture, but there have been few attempts to put the practice to objective test. There are those who would say the benefits are too obvious to need test, and it is true that the health of arable crops on land that has been allowed to become infested with soil-borne pests or diseases of arable crops can be strikingly improved by a period under grass. Also, the improvement after a neglected pasture is ploughed up and reseeded is usually self-evident. However, there are other methods of controlling soil-borne pests and diseases than a period under ley, and neglected pastures can be improved in other ways than by ploughing and reseeding; indeed, ploughed and reseeded pasture usually gets managed and manured in ways denied to old pasture, and benefits produced by these other changes may be being wrongly attributed to ploughing and reseeding. The apparently self-evident benefits of ley farming, therefore, fall far short of providing the evidence needed to decide whether, on any given area of land, ley farming is more productive per acre than keeping some of the land continuously under arable crops and some under permanent pasture. It is difficult to get such evidence, which requires complex experiments that continue for many years. The ley–arable experiment was started at Rothamsted in 1949 to provide some of the evidence, and some of the answers now begin to emerge. It followed a smaller experiment at Woburn, where the yields of potatoes and barley following 3 years of leys were little better than those in continuous arable cropping, even though on this light soil beneficial effects on soil structure might have been expected from the leys.

At Rothamsted the experiment is in two halves, one on Highfield, which had been permanent grass for very many years, and the other on Fosters, which had for long been under arable crops. In neither half has the system of ley farming produced arable crops that are strikingly better than those produced in the continuously arable rotation, provided only that the crops in the arable rotation were adequately manured. The one exception to this is that, on Fosters, wheat after lucerne has consistently yielded more than after any other treatment, but after grass leys yields have often been less than after arable crops. At first, potatoes yielded better in the ley–arable rotation than in the continuously arable, but since the amount of fertiliser given to the crop has been increased, potatoes have yielded similarly with all the treatments. Considering the difference in the past history of Highfield and Fosters, yields have been perhaps unexpectedly similar on the two halves of the experiment, but more fertiliser has been needed to give high yields on Fosters than on Highfield; for the first 6 years cereals did not respond to nitrogen on Highfield (though grass did), and only recently have responses become economic and approached those on Fosters.

On Highfield ploughing up the old grass and reseeding has had

little effect on productivity, for the old grass left in place, reseeded grass left to grow indefinitely and 3-year leys, have all given about the same weight of dry matter per acre. On Fosters, too, temporary leys have produced no more than land put under permanent grass. In other places leys may be more productive than at Rothamsted, and periods under grass elsewhere may have beneficial effects on arable crops denied to us; this information should come from tests of ley-farming now being made on some of the Husbandry Farms of the National Agricultural Advisory Service, but meanwhile we can only report that in our conditions the practice has little to recommend it, provided that the rotations of arable crops avoid major soil-borne pests and diseases and that both arable crops and permanent grass are adequately manured.

The two halves of the experiment also show how impossible it is to generalise about the effects of a given practice on the state of the soil. On Highfield the organic matter of the soil has decreased steadily since the ley–arable experiment began, not only where arable crops are taken every year but also where they alternate with leys, whereas on Fosters the ley–arable rotation is steadily increasing the amount of organic matter in the soil.

Soils and fertilisers

The manurial experiment with mangolds grown continuously on Barnfield since 1876 ended in 1959 and has left a legacy of soils with very different contents of plant nutrients. This year we summarise the effects of the various types of manuring on yield of both mangolds and sugar beet, which were introduced into the experiment in 1946, and describe the changes in responses over the years, not all of which can be satisfactorily explained. The cropping and manuring will now be altered in ways that are hoped will explain some present puzzles and provide new information about the value to current crops of residues from past dressings of organic and inorganic manures. Particularly, the separate actions of magnesium and sodium will be assessed and tests will be made to see whether increasing the amount of inorganic nitrogen given will achieve yields so far attained only by farmyard manure plus inorganic nitrogen.

Results are reported of many other manurial experiments, on grass and most of the common arable crops, testing different kinds and forms of fertilisers, and different ways and times of applying them. Applying nitrogenous fertilisers as solutions to grass seems a practice not to be recommended, for it has consistently given slightly smaller responses than applying them as solids. Urea, which is being increasingly used, is more likely than other forms of nitrogenous fertilisers to damage germinating cereal seed, and only with urea is it worth using a side-band drill. Combine drilling and broadcasting other forms give yields similar to those obtained from side placement, but to use urea efficiently requires placing it at the side of the seed, and the extra yield from placement quickly repays the cost of the equipment needed to do it.

An interesting and potentially important addition to its value as a fertiliser was found for ammonium sulphate in apple orchards in Cambridgeshire, where apple scab starts each year from ascospores of the fungus (*Venturia inaequalis*) that survive the winter in fallen

leaves. Broadcasting 3 cwt./acre ammonium sulphate 3 weeks before the time of bud-burst destroyed more than 90% of the ascospores that otherwise would have been liberated and provided sources of infection for the new growth.

Work with Broadbalk soils shows considerable effects of mineral fertilisers on crumb structure and porosity. That these properties are improved by organic manures is generally assumed, and few will be surprised by the fact that soil from the farmyard-manure plot has a better structure than that from the unmanured plot. However, it is no better than the structure on plots 8 and 16, which get only mineral fertilisers, so the improvement seems not to be a direct effect of the farmyard manure on the soil, but indirect by its nutrients increasing plant growth, and can be produced equally by mineral fertilisers that stimulate plant growth equally.

As we have previously reported that inoculating seed with *Azotobacter* sometimes increased yields of crops, it is necessary to say that this year there was no response in five field experiments with the "bacterial fertiliser". However, the *Azotobacter* did not establish well, probably because the soils used for the tests were too acid. Conditions for getting the bacterium established in the rhizosphere of crops are beginning to be better defined, so the prospects of getting consistent results seem brighter, and then perhaps its actions will become interpretable.

The many other lines of work with soils and manures reported this year, and not mentioned here, describe new information about factors affecting aeration, the manner in which major nutrients and trace elements are held in soil, the factors that affect their availability to plants, the break-down of organic matter of different types, the effects of soil conditions on soil organisms and of soil organisms on soil conditions.

Varietal differences in yield

The increases in yields of most crops over recent years have many causes, improved manuring, earlier sowing and less lost to pests and diseases or to competition from weeds. With some crops, such as potatoes, the whole increase is attributable to improved methods of cultivations, for the varieties now generally grown are the same as previously, but with cereals the increased yield is partly attributable to the introduction of higher-yielding varieties. There has been little work on the factors responsible for varietal differences in yield, so we have analysed the growth differences between new and old varieties of barley and of wheat (spring and winter). One difference between the two varieties of winter wheat that affects yield is that the old one (Squarehead's Master) lodges at levels of manuring where the shorter-strawed Cappelle remains erect, but the main difference is that the ears of Cappelle photosynthesise more and contribute more to the yield of grain than do the ears of Squarehead's Master. Similarly, the new varieties of barley and of spring wheat also yield more than the old because the ears assimilate more, and not because of increased leaf area or increased assimilation rate in the leaves. Such comparisons cannot show whether intrinsic yielding capacity can be increased in other ways, but the fact that the same principle

is operating in barley as in both winter and spring wheat suggests that this one is probably more readily changed than others.

Leaf protein

The work on producing leaf protein suitable for human consumption progressed at all stages of the process, from the selection of suitable plants to improvements in the methods of extracting the protein and of preserving it once prepared. The last is dietetically important, for the nutritive value is lowered by over-heating during drying. However, perhaps the most valuable progress was in the increasing interest shown in the work by organisations in several tropical countries where protein deficiency is a major cause of malnutrition. We have done the necessary work to establish that a nutritionally desirable protein, which would make a valuable supplement to diet, can be made, but whether it can be made economically where it is most needed can be established only by a thorough test in the countries where work is now beginning.

The use of pesticides

The use of toxic chemicals in agriculture is a subject that receives much publicity, usually emphasising hazards, real or imagined, rather than the benefits. We again record many examples of the large increases in yield that can result from using appropriate pesticides, and agriculture obviously cannot afford to forgo such increases. However, it would be foolish to expect that yield increases are their only effects and that they do nothing except kill the pests at which they are aimed. The need to assess probable other effects is the reason for much of our work on the stability of insecticides in different environments and on the different ways they act; also for our population studies, not only of pests but also of other organisms, particularly those usually described as beneficial. Increasing attention is now being given to the soil fauna and flora, for it is in rather than over the soil that residues from pesticides can be expected to accumulate and perhaps have lasting consequences. The major effects we describe of long-continued spraying with copper fungicides on the soil and soil fauna in some apple orchards show the kind of thing that can happen when residues accumulate. The need for more knowledge is urgent, because pesticides are likely to be applied to the soil much more than they have been; until now, this has been done only to control soil-inhabiting pests, but, as our report shows, there is increasing likelihood of it being done to control foliage pests such as aphids. Systemic insecticides applied to seeds, to potato seed tubers or to the soil at time of sowing can keep plants free from colonising aphids for several weeks, so protecting seedlings from pests and vectors of viruses while they are too small to be sprayed effectively; it is also cheaper than spraying, is less likely to affect predators of aphids and avoids the chance of drift or of the chemical harming anything that does not actually feed on the crop. Some of these advantages might also come by replacing spraying by dusting crops with granulated forms of insecticides, which this year was as effective as spraying in checking sugar-beet yellows, but this again would probably increase the amount of insecticide that enters the soil.

Fortunately, most such insecticides are unstable and will soon be destroyed in soil, so any effects they have on the soil fauna are likely to be temporary only. Tests of nematicides at Woburn showed how brief effects can be from soil treatments that have immense effects on crop yields. Applying a nematicide to land heavily infested with potato-root eelworm increased the yield of Majestic potatoes from 4 cwt. to over 11 tons/acre, but the eelworm population was only temporarily made harmless. After harvest, there were as many eelworm cysts on the treated as the untreated plots, for the few eelworms remaining after the treatment, presented with abundant roots on the vigorous potato crops, multiplied abundantly and restored their initial population within a year. Similar rapid changes in population are not peculiar to eelworms, but are to be expected with all rapidly multiplying organisms when exposed to transient conditions that limit their numbers. Essentially the same phenomenon is described after spraying sugar-beet crops with organophosphorus compounds. For a time the sprayed crops were free from both aphids and their ladybird predators (which probably disappeared more because they had nothing to eat rather than because the spray killed them), but as the insecticidal action wore off, first aphids and soon after ladybirds recolonised the sprayed crops, and within a few weeks populations of both were the same in both sprayed and unsprayed crops.

However, not all the chemicals used to protect plants are unstable, and it is the stable ones that are mainly applied to soil. If, as our preliminary tests suggest, some of the chlorinated hydrocarbons are also fungicidal and may affect such diseases as take-all, their use might increase still further. To assess the consequences, we are studying their effects, not only in checking pests and diseases, but on the whole soil fauna, and are measuring the rates at which they disappear in soil. That they change the fauna greatly is already clear, but whether residues will accumulate and produce lasting changes, and, if so, whether these will be harmful or beneficial to crops, remains to be discovered. So, too, does much of the biological knowledge that is needed before pesticides can be used most economically and with the least risk of side effects, whether of killing organisms other than those the pesticide is aimed against or of producing forms of pests that resist current insecticides. Without this knowledge, which we seek from our work on the factors that determine the multiplication and behaviour of pests, pesticides will be used as a routine insurance against possible losses and not only where benefits from their use are assured. The epidemiology of some pests and diseases is already sufficiently understood to forecast when and where pesticides are needed, and for the control of these anything but discriminate use is clearly imprudent, but this is not yet generally true. Until it is, farmers cannot know when they can safely dispense with a pesticide and thereby save its cost, and most will consider it as improvident not to use a cheap and effective pesticide routinely as they would not to insure against losses from fire.

Bees

That the use of insecticides does have undesirable results is evident enough from the poisoning of bees; of forty-five samples sent to us this year suspected of being poisoned, thirty-two contained insecticides and one had probably been killed by a fungicide containing mercury. To what extent these poisonings happen when pesticides are being used as recommended, it is impossible to tell, but that misuse and carelessness sometimes play a part is more than suggested by finding that one hive in which bees had died had been "protected" by being covered with a sack that had contained insecticidal seed-dressings.

Tests with synthetic queen substance show that this is not the only chemical that queen bees produce to inhibit workers from rearing new queens; another is volatile, seems to be produced by glands in several parts of the body, and both it and the queen substance are needed to stop queen rearing completely. Neither seems to be the scent whereby a queen attracts bees over a distance, and it is obvious that identifying queen substance is only a start towards understanding the full chemical mechanisms whereby queen bees rule their workers.

Pollination studies suggest that pollination is increased by feeding colonies syrup before taking them to the crop to be pollinated and that they should not be taken there until the crop is flowering; also, methods currently recommended for arranging pollinator varieties in orchards of self-sterile fruit trees seem not those likely to give the maximum set of fruit.

An unwelcome catch

Insect and spore traps are operated regularly to give quantitative and qualitative information about the biological contents of the air. In two previous years a few spores were caught of *Pithomyces chartarum*, a fungus not previously reported in Europe, which in New Zealand produces a toxin, sporidesmin, responsible for the serious disease of sheep known as facial eczema. This year portable spore traps were used to sample air in several places, and high concentrations of spores were found in some, which were then searched and the fungus found growing on the remains of cut grass. Whether the British strains produce sporidesmin is being tested in collaboration with workers in New Zealand.

A welcome gift

We gratefully acknowledge the gift from Elliott Brothers of a 402 computer, which will not only relieve the over-burdened 401 but will ease the transition in 1963 to the Orion with its much greater capacity than the 401. The 402 will be used mostly to analyse surveys, and the General Survey Programme has already been transcribed for it. A General Experiments Programme to analyse replicated experiments of many different designs is now almost complete. The amount of computation in the Statistics Department increased by more than a third over that of 1960, and was concerned with problems about as diverse as they possibly could be. Most, of

course, were agricultural; these ranged from surveys of fertiliser practice and cattle fertility to forecasting cocoa yields in Ghana for the next 10 years and analysing long-term experiments on coconuts in Ceylon; but they obviously did not tax the versatility of our statisticians, whose other work extended to studies on the capture and recapture of bats and intelligence tests in children, to the planning of motorways and the age of menarche in Bantu girls.

PHYSICS DEPARTMENT

H. L. Penman

D. A. Rose, an Agricultural Research Council Scholar working in the department, was appointed to the staff in January. Dr. K. Yabuki returned to the University of Osaka, Japan, after a year's work on carbon dioxide exchanges between soil, crop and atmosphere, and Dr. G. Contreras returned to Madrid after studying the effect of fertiliser treatment on water-holding capacity of soil (Broadbalk) and crop/weather relationships (six-course experiment). For six months, Dr. P. Gaastra, a plant physiologist from Wageningen, Holland, joined J. L. Monteith for an exchange of ideas on problems of plant growth, a visit made possible by the award of an O.E.E.C. Fellowship. In November Dr. R. Shapiro, from Beltsville, Maryland, came to spend a year working on nutrient release and diffusion in soils, and in December, Mr. C. E. Hounam, Bureau of Meteorology, Australia, arrived for a two-month study of problems and techniques in agricultural meteorology.

Soil Physics

Soil aeration

A good soil provides firm anchorage for plant roots without undue constraint on their growth as they acquire food, water and air. The pore-space is determined by the nature of the soil particles, by the way in which the particles are assembled in aggregates and by the way in which the aggregates are packed together, and normally it is occupied partly by water and partly by air. For adequate air supply and adequate water supply a compromise is required between the extremes of maximum water content and maximum air content, and although " adequate water supply " can now be specified with some confidence, " adequate air supply " is, quantitatively, a much vaguer concept. Qualitatively, the problem is clear. During healthy growth plant roots absorb oxygen and evolve carbon dioxide, so altering the composition of the air in the soil, and unless the oxygen is replaced and the carbon dioxide is removed the concentration of either gas may reach a value at which plant growth is inhibited and the soil becomes essentially anaerobic. If there is continuity of air-filled pore-space between the root environment and the free atmosphere, then both gases will interchange between soil and atmosphere by molecular diffusion, a process conveniently termed " aeration ". Our quantitative study of the physics of aeration therefore started from study of molecular diffusion in porous systems and how it is affected by particle properties, by aggregate properties and by variable water content.

If the coefficient of diffusion of a gas in free air is D_0, then in a porous solid it will be decreased to an effective value D such that $0 \leqslant D/D_0 \leqslant \varepsilon$, where ε is the fraction of pore-space that is air-filled. For loose dry particles the value of D/D_0 is determined partly by ε

and partly by the shapes of the pores, and as these depend to some extent on the geometry of the particles, D/D_0 can be expressed in terms of ε and a particle-shape factor (k or m). In a dry aggregated material such as soil the particle-shape factor has much less significance, but values of k or m deduced from diffusion experiments can be interpreted as soil complexity factors; in fact, they are structural indices. When there is water in the system it tends to produce some uniformity of pore shape, and its effect on D/D_0 depends very much on the distribution of the water between the small pores in the crumbs and the large pores separating the crumbs. If the crumbs are " solid ", as they are in sand, or, in effect, in a soil whose aggregates are completely waterlogged, then D/D_0 varies as the fourth power of the remaining air-filled pore space, a relationship that implies a rapid increase in D/D_0 in the final stages of removal of water from the inter-crumb pore-space. Further drying takes water out of the crumbs themselves, but the increase in D/D_0 per unit increase in total air-filled pore-space is now relatively very much smaller, and crumb porosity does not contribute much to bulk aeration of the soil, though it does contribute nearly all of the water-holding capacity of the soil. This broad summary of the implications of the first results of the work on diffusion leads to a general specification of a well-tilled soil as one that allows adequate diffusion down the profile between the crumbs and yet leaves the crumbs with adequate pore space to contain and retain water at field capacity.

With the basic physical relationships established, the next phase was mathematical. Given values for the oxygen requirement of a soil (that is of roots and of soil organisms), the distribution of gas composition with depth in the profile can be calculated for various assumed forms of pore-space distribution. An important result emerged. Unless the value for oxygen requirement is absurdly high, or the packing is such that D/D_0 is absurdly low, it is impossible to predict gas concentrations in the inter-crumb pore-space which are likely to limit plant growth even in soils where poor aeration is suspected. The mathematical analysis was then pressed further, recognising that the composition of the soil air does not necessarily represent the condition at the root surface, because the diffusion path has to be completed through a film of water on the root hair. The rate of diffusion of oxygen in water is only about 10^{-4} times its value in air, and, as a further complication, oxygen is so much less soluble than carbon dioxide that the relative concentrations of the two gases in solution may be the reverse of those in air with which the solution is in equilibrium. Except during the day or two needed to bring the soil to field capacity after rain, the aeration problem lies in what happens between the outside and inside of a crumb.

As a help towards understanding, and a guide towards experiment, a crumb can be idealised as a sphere with respiratory activity uniformly distributed throughout its volume. For such a system, in equilibrium with its environment, the concentration of a diffusing gas at a distance r from the centre is

$$\delta_r = \delta_a + S_c\,(a^2-r^2)/6D_c \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

where δ_a is the concentration at the surface, a is the radius of the sphere, S_c is the respiratory activity per unit volume of sphere and

D_c is the coefficient of diffusion of the gas through the pores. As the size of the sphere increases, the oxygen deficit increases; and for a given size the same effect is produced by decrease in D_c, which may happen for several reasons. Furthermore, as crumbs become wetter, gaseous continuity is decreased and ultimately diffusion is restricted to movement through the water. Under such circumstances the oxygen deficit may be large enough for the centre of the crumb to be effectively anaerobic. For further analysis we can measure or calculate values of δ_a, a and S_c with adequate accuracy: the real problem is to get an estimate of D_r. Some progress has been made in the analysis (1.4) concluding ". . . whereas it is clearly impossible to calculate a universally acceptable ' optimum crumb size ', it seems possible to estimate the crumb size for a given soil that would preclude the onset of anaerobic conditions in the range between wilting point and field capacity most prevalent during the season of active crop growth ".

Direct measurement of diffusion within the micro-structure of a crumb is difficult, but some measurements have been made with sufficient precision to test alternative theoretical analyses. Large synthetic crumbs are made by powdering dry soil, packing it into a cylindrical mould, wetting it and allowing it to dry into a coherent mass. Using the standard hydrogen technique, a value of D_c is measured. As a supplement, an indirect estimate is then made. The dry block is crushed and the 1–2-mm. fraction sieved out and repacked in the container. A diffusion measurement is made on this material, to give a value of D_r, say, and is then repeated after the crumbs have been saturated with paraffin (kerosene) and drained under tension until all the inter-crumb pores are air filled and the crumbs themselves remain just fully saturated, the second operation giving a value D_v, say. (The use of paraffin instead of water avoids swelling complications.) The difference D_r–D_v is a measure of the contribution of the crumbs to the total diffusion, but it is not a unique measure of diffusion in the crumbs, because it shows some dependence on the way the crumbs are packed, and on the shape of the crumbs.

Of the two theoretical expressions available the simpler is

$$D_c/D_0 = (D_r\text{–}D_v)/(D_0 - D_v) \quad . \quad . \quad . \quad (2)$$

and over the range of soils studied it over-estimates the value of D_c/D_0. This particular equation comes from the treatment that led to the particle-shape parameter k. The second, more complex, equation comes from the treatment that led to the particle shape factor m, and it underestimates the value of D_c/D_0. But both expressions for D_c/D_0 put a given series of soils in the same order. Using the indirect method on natural soils, it is clear that the microstructures of crumbs vary in their ability to transmit gases by diffusion, and it is useful to introduce crumb complexity factors k_c and m_c (analogous to the bulk soil factors k and m) to express this variation quantitatively. The values are

$$k_c = \{\varepsilon_c/(1 - \varepsilon_c)\}\{(D_0/D_c) - 1\} \quad . \quad . \quad . \quad . \quad (3)$$

$$m_c = \log (D_c/D_0)/\log \varepsilon_c \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

where ε_c is the porosity of the crumb.

The technique was applied to crumbs from four of the Broadbalk plots, and Table 1 gives values derived from the simpler expression for D_c/D_0 (eq. 2).

TABLE 1

Complexity factor for crumb micro-structure (Broadbalk)

Plot	Treatment	Crumb Porosity (ϵ_c)	D_c/D_0 (eq. 2)	k_e (eq. 3)
3	No fertiliser	0·222	0·036	7·6
2	FYM	0·274	0·063	5·6
8	Sulphate of ammonia + minerals	0·264	0·061	5·6
16	Nitrate of soda + minerals	0·267	0·057	6·1

The soil on the unmanured plot has failed to attain (or maintain) the same crumb porosity as the other three plots, and it has a greater crumb complexity. The uniformity of the other three plots suggests that it is the activity of plant growth (all produce big yields) that is correlated with these particular measures of crumb structure, and that the dung has had no extra effect on either crumb porosity or complexity.

Table 1 is for dry crumbs, and the next stage of the work will be an attempt to make similar measurements on crumbs wetted over the range experienced by soils in the field.

Soil structure

Spring beans were again grown in the second test year after ploughing out former ley and fallow plots. Half of each plot was deliberately cultivated at the wrong time to degrade the known better structure of the former ley plots, and to worsen further the poorer structure of the former fallow plots. A satisfactory level of bad farming was achieved by disc harrowing the soil when it was very wet.

Plant population and plant height were lower on the mismanaged half plots, and yields were about 20% less. The contrast was about the same between former ley and former fallow plots, i.e., in a self-evident shorthand, ley + good cultivation > ley + bad cultivation = fallow + good cultivation > fallow + bad cultivation. (Currie.)

Soil water

Measurement of the movement of water vapour in soils continued, and results are now being prepared for publication. Leaving a summary until a later report, a minor by-product is worth notice. Subsidiary experiments on the effect of salt in the soil water suggest that placed fertiliser will not be a serious competitor with seeds in their need for soil water (1.10).

Some incomplete measurements of the " available " water in the profiles of Broadbalk plots 2A, 3 and 8, based on the pF meter of Monteith and Owen, agree very well with those of Balcerek and Russell in 1945 obtained by a completely different technique. In the top few inches the available water of the FYM plot (2) is about 40% greater than that of the unmanured plot (3). Below about 15 inches the difference is the other way round, but the information is

not complete for the whole depth that might be explored by plant roots. (Rose and Contreras.)

Soil water

The neutron-scattering technique for estimating soil water content is at last in the form we wanted. The delay has not been unrewarding, for the unit is better than it could have been even a year ago, and within the volume of a portable radio set the unit has a self-contained power supply, a five-decade counter, a rate meter and weighs only 14 lb. (Long.)

Electrical charges on clays

In the preparation of material to study the effects of different cations on the behaviour of clays, the early stages aim at producing a homo-ionic clay free from exchangeable aluminium. In the course of the experiments the aluminium inevitably reappears, and as it must come from the clay, it is presumed that there is degradation of the edges of the crystallites, a result of the strain produced by an electrical potential difference between the edges (positive) and the planar faces (negative). Reasoning indicates that the aluminium in the detritus—detectable as exchangeable aluminium —should be equivalent to the known positive edge charge of the clay in acid solution (1.3). An extensive series of proving experiments has produced conflicting results. The qualitative behaviour is as predicted: some of the quantitative results are as expected, but not all, for there seems to be too much aluminium coming out of the lattice. It may be that we are detecting a phenomenon suspected some years ago by Greene-Kelly—that the hydrogen ions in the wash water may release aluminium from the clay lattice. If so, then these special conditions of a laboratory experiment may be relevant to the field conditions that produce " weathering " of clays. (Cashen.)

Agricultural Meteorology

Micro-meteorology

The measurement of temperature, humidity and wind profiles over grass continued until the end of the summer, so completing three years' observations. Re-calibration of the soil thermometers, buried for three years, showed no change greater than 0·1° C.

Two sets of equipment were run close together in a crop of beans on the western half of the same field. The first was our standard equipment. The second was a system of aspirated wet- and dry-bulb units which had to be specially built for the purpose, and involved some trouble in finding a suitable pump for the aspiration. Although aspiration gets over the difficulty of having to use a variable psychrometer constant (not that it has ever embarrassed us, though others have challenged our practice), it has brought in new troubles of its own, particularly at low wind speed, where there is some evidence that it disturbs the natural air flow. Analysis of the records is, however, far from complete.

A set of fifty-two bi-directional vanes, mounted in four tiers on

a large wind vane (about 12 feet long, 4 feet high), was built to get some idea of the nature of the turbulence in the air over a crop, partly for its own meteorological interest in adding to understanding of heat, vapour and carbon dioxide transfers, and partly to get some knowledge of the first (or last) stages of the movement of insects or spores from (or to) a crop. Records, taken with a ciné camera, look good, but no analysis has yet been attempted. (Long.)

Radiation balance

As a complement to previous work on radiation components, the diurnal variation of effective surface radiative temperature was measured on cloudless days, over a variety of surfaces. (Once again, we are grateful to Professor P. A. Sheppard for the loan of a Linke–Feussner radiometer for this work.) Loose bare soil showed the greatest diurnal range, a maximum of 44° C. being estimated on a day when the maximum air temperature reached 25° C., and water surfaces experienced least diurnal variation. Several kinds of vegetation, other than short grass, behaved much alike, and the inter-relationship of surface temperature and net radiation was consistent with a theoretical model of heat and vapour transfer from leaves to atmosphere.

Analysis of our own solar-radiation records, and of those from Meteorological Office stations, produced a way of estimating mean solar-radiation intensity in the presence of cloud and atmospheric pollution. Combination of this with previous work on long-wave radiation now makes it possible to estimate the seasonal variation of net radiation for natural surfaces almost anywhere in the British Isles. "Net radiation" is the dominant term in estimates of potential evaporation, as made here and elsewhere, and this new work should remove some of the hitherto unavoidable crudities of our present method of estimating evaporation from weather data. First computations suggest that there is little difference in evaporation between south England and north Scotland; and that the evaporation rate from a standard M.O. tank is almost independent of wind speed and humidity—the tank is, effectively, a net radiometer.

Water balance

A second transpiration gauge, built by the Cambridge University Engineering Laboratory, was installed in March on the same section of Great Field, about 200 yards west of the first balance. The crop on the second site was spring beans: the first site continued under grass (grown for hay) and although the ratio of transpiration from grass and from beans varied from week to week, the totals from 29 April to 3 September were not very different: 10·7 inches for grass, 9·9 inches for beans, while the totals for two open water evaporimeters nearby were 14·3 inches for a standard M.O. tank and 16·0 inches for a U.S.D.A. Class A pan. (In the same period the estimated total potential transpiration at Woburn was 12·1 inches.) For three weeks at the beginning of May transpiration from the grass was 50% greater than from the M.O. tank, but from June onward transpiration from both grass and beans was

consistently less than the open water evaporation, indicating a shortage of soil water.

Further study of the energetics of condensation has led to the concept of " potential condensation " as the maximum possible rate of dew formation. Calculated values agree well with observations in various parts of the world (1.5).

Carbon dioxide balance

The six-point gas analyser was used throughout the summer to measure the vertical distribution of concentration in and above grass and beans, horizontal variations downwind from the edge of a crop and absolute concentrations over different crops at the same time. The carbon dioxide flux from the soil was measured gravimetrically by absorption in soda lime, and volumetrically by absorption in baryta, and the latter technique was adapted for electrical recording. As orders of magnitude, the winter flux was 0·1 mg./cm.^{2}/day (= 10 lb./acre/day) and the summer flux beneath a crop was 1·0 mg./cm.^{2}/day, a major contribution to crop assimilation (2–3 mg./cm.^{2}/day). To assist interpretation, laboratory measurements of rates of photosynthesis and respiration were made on single leaves at controlled levels of CO_2 concentration, light intensity, temperature and humidity.

Radiometry

A miniature net radiometer (diameter 4 cm.) was made for the Hannah Dairy Research Institute for measuring the radiation balance of grazing sheep, and a similar instrument was sent to Dr. G. Stanhill, National and University Institute of Agriculture, Israel, who is using several Rothamsted devices in his crop-water studies, a consequence of Monteith's visit to Israel in 1959 (1.2). Another radiometer, and some of Long's micro-meteorological equipment were lent to the British Schools' Exploring Society expedition to Central Iceland in 1960, and their recent report indicates that performance was good. Israel and Iceland provide a fair climatic range for proving trials of our equipment.

Nearer home, equipment for integrating solar radiation and net radiation was installed at Woburn (described in 1.6). A new design, modified to satisfy a new need, will measure energy in the photosynthetic wavelength range, 0·4–0·7 μ, and is now being tested. (Monteith, Szeicz, Yabuki, Gaastra.)

Woburn irrigation experiment, 1961

Except for one wet week in June, and another in July, this was a dry summer up to the beginning of August. The equipment was in use from mid-May until August, and all crops responded to irrigation. *Grass*: For a second-year crop, growth was rather poor, and after diagnosis of impeded drainage it was decided to plough up the plots in September, and to subsoil afterwards. Without irrigation, there was no important response to nitrogen, or potassium, or both. There was a big response to irrigation under all fertiliser treatments, but within the watered treatments three gave almost the same yield, with the fourth (high N, high K) outstanding.

Laboratory work has started to find out why this Woburn soil can supply enough potassium to produce about 4 tons/acre, but needs a supplement to get the yield up to 5 tons/acre of dry matter. *Spring beans*: The end of 1960 was too wet for husbandry, and the crop intended—winter beans—could not be drilled. The response to irrigation was better than any previously obtained (1957–59). *Barley*: The response to water was about the same as to extra nitrogen: it is usually smaller. *Early potatoes*: The yields in the table are for plots given normal cultivations. Six of the twelve had minimum cultivation and a simazine spray to try to control weeds. It was not very successful, and yields suffered, the average of the unwatered plots being 4·8 tons/acre and of the irrigated plots, 8·8 tons/acre. (Penman and Barnes.)

TABLE 2

Woburn Irrigation, 1961

Crop	Period	Rain (inches)	Irrigation (inches)	Plot	Yield	
Grass	1 May–11 Sept.	6·6	—	O	45	Dry matter, cwt./acre. 6 cuts
				C	70	
		6·6	6·0	except CKN_4	98	
Spring beans	1 May–21 Aug.	5·4	—	O	14	Grain, cwt./acre
		5·4	4·5	C	32	
Barley	1 May–31 July	3·6	—	ON_1	24	Grain, cwt./acre
				ON_2	32	
		3·6	3·2	CN_1	30	
				CN_2	37	
Early potatoes	1 May–10 July	2·5	—	ON_1	5·9	Tubers, tons/acre
				ON_2	6·9	
		2·5	4·0	CN_1	13·3	
				CN_2	15·0	

CHEMISTRY DEPARTMENT

G. W. Cooke

F. J. Seabrook completed fifty years of service to Rothamsted in May 1961. We were delighted that he was awarded the British Empire Medal in the Queen's Birthday Honours List.

M. St. J. Foale left at the end of the year. In June P. W. Arnold and G. W. Cooke visited research institutes, experimental farms and a potash-producing mine in Germany as guests of Verkaufsgemeinschaft Deutscher Kaliwerke G.m.b.H. Several members of the Department attended a very successful conference of the British Society of Soil Science in Dublin in September. Cooke visited research institutes and fertiliser-producing plants during a meeting of the Fertiliser Society in Holland in March. During a private visit to Israel, B. Benzian was a guest of Dead Sea Works Ltd. for a few days and visited research institutes and forest nurseries.

The following worked in the Department during the year: Dr. N. J. Barrow (Australia), Dr. A. Karim (Pakistan), Mr. Y. C. Lin (Hong Kong), Mr. S. Oliver (Spain), Mr. R. C. Salmon (Rhodesia), Mrs. Branka Savic (Yugoslavia), Dr. R. E. Shapiro (U.S.A.), Dr. L. V. Vaidyanathan (India), Mr. L. Verini (Italy), Dr. J. M. Walker (U.S.A.) and Dr. Y. Yamada (Japan). Vaidyanathan obtained the Ph.D. Degree of London University.

Organic Manures and Soil Organic Matter

Farmyard manure

In our programme of work intended to show how farmyard manure (FYM) affects crops, an experiment at Woburn compared 7·5 and 15 tons/acre of FYM (supplying 150 and 300 lb. K_2O/acre) for sugar beet with three NK fertilisers supplying the same amounts of K_2O. The $N : K_2O$ ratios of the fertilisers tested were 2 : 10, 3 : 10 and 4 : 10, providing from 30 to 120 lb. N/acre. Sodium chloride supplying as much Na as 15 tons/acre of FYM was also tested; superphosphate (1·5 cwt. P_2O_5/acre) and magnesium sulphate (50 lb. Mg/acre) were given to all plots. Such high concentrations of fertiliser salts applied to the seedbed harmed germination in 1960, so all fertilisers were dug in in late March in 1961.

There were good increases in yield from FYM and from NK fertilisers, but no extra increase from applying sodium as well. Yields of roots and sugar from FYM treatments were close to those from the fertiliser with $N : K_2O$ ratio of 4 : 10; 15 tons/acre of FYM gave 70 cwt./acre of sugar and the fertiliser gave 69 cwt. Although these yields were about 40% greater than the yields from plots receiving no N or K, the response curves with the 4 : 10 ratio fertiliser, and with FYM, did not reach a maximum. In contrast, the other two fertilisers with $N : K_2O$ ratios of 2 : 10 and 3 : 10 gave only small increases for the extra nutrients supplied by the double

rate, although at the single rate they were as good as the single rates of both FYM and of fertiliser with N : K_2O ratio 4 : 10.

Yields of tops behaved differently and were directly proportional to the amounts of N supplied by the fertilisers: the 4 : 10 ratio fertiliser was best; it supplied 120 lb. N acre at the high rate and gave 7 tons acre of extra tops. The tops response curve with FYM was also linear and was almost identical with the curve for the 2 : 10 ratio fertiliser, but not with the 4 : 10 ratio fertiliser.

Yields of roots and sugar with FYM were equalled by using 4 : 10 ratio NK fertiliser, but this fertiliser gave 4 tons acre more tops. Lowering the amount of fertiliser-N to decrease top growth, while maintaining the same level of K as was supplied by FYM, also lowered the yields of roots and sugar. We have no explanation for these differences between FYM and fertilisers; the sodium supplied by the FYM was not the cause, and it is unlikely that magnesium was a factor, because a basal dressing was given. (Warren and Johnston.)

Liquid manures

Some modern methods of keeping stock indoors continuously produce large volumes of liquid manure. As it may become illegal in some places to run these effluents into sewers or streams, their value as manures applied direct to land is being considered. Several samples of liquids resulting from intensive pig-keeping were analysed; two extreme results were:

	Sample 1	Sample 2
	(% (w/v))	
Total solids	4·1	7·5
N *	0·3	0·9
P_2O_5	0·2	0·7
K_2O	0·1	0·7

* Of the total N, more than two-thirds was ammonium.

Both liquids were valuable sources of N, P and K; 1,000 gallons of sample 2 supplied about 90 lb. of N, 70 lb. of P_2O_5 and 70 lb. of K_2O. Where large volumes of such effluents are produced, they are important sources of plant nutrients, and they should be used efficiently. More research may be needed on the best ways of conserving the N, P and K, and of applying the liquids. (Williams and Cooke.)

Decomposition of labelled plant material in soil

The experiments started in April 1959 (*Rep. Rothamst. exp. Sta.* for 1960, p. 43) continued with two soils from Broadbalk, viz. Plot 2B, which receives FYM each year and contains 2·4% carbon, and Plot 3, which receives no FYM or fertilisers and contains only 1·0% C. After one year in the field about a third of the added plant carbon remained in soil, and after two years about a quarter; losses were the same in both soils. Similar amounts of plant carbon were lost under "natural" conditions in the field as in laboratory incubations at 25°. Very long incubation periods will be needed to measure rates of turnover of the inert fractions of soil organic matter accurately.

The distribution of newly-added labelled plant material throughout the soil organic matter, after it has decomposed for a year in the field, is being examined by both chemical and biological methods. Several of the chemical methods partially differentiated between new and old organic matter. The most striking effect was with cold 0·1N-HCl, which dissolved less than 1% of the total organic carbon of the soil, but one-tenth of this was derived from the added labelled plant carbon. Some separation of the new organic matter was obtained by treatments involving 6N-HCl, cold anhydrous formic acid and 2·5% H_2O_2. The humic acid fraction isolated from an alkaline extract had a smaller percentage of labelled carbon than the fulvic acid fraction.

Biological fractionation was done by measuring the labelled and unlabelled CO_2 evolved from soils incubated for 10 days at 25° after they had been pretreated in various ways. The percentage of labelled CO_2 evolved from soil from Plot 2B was six times as much as in the soil organic matter as a whole; for soil from Plot 3 the CO_2 evolved was four times as rich in labelled C as the soil organic matter. Oven-drying the moist soil, or exposing it to chloroform vapour, increased both the total CO_2 evolved, and also the percentage of labelled C in the CO_2. When the soil was oven-dried at 80° before incubation, more CO_2 was evolved than with any of the other pretreatments, although the percentage of labelled carbon in the CO_2 evolved was slightly less than after pretreatment with chloroform. Five successive oven dryings and incubations removed about 5% of the total amount of organic carbon in soil from Plot 2B, and this contained one-quarter of all the labelled carbon; 7% of all the carbon in soil from Plot 3 was lost by the same treatment, and this also contained one-quarter of all the labelled carbon present. The amounts of labelled carbon evolved fell off much more rapidly with successive incubations than the amounts of unlabelled carbon. When these experiments were repeated after the soils had spent a further year in the field the labelled carbon evolved on incubating the undried soil at the end of the second year fell to roughly half the corresponding value for one year. The labelled carbon evolved after oven drying was two-thirds the value obtained after one year in the field.

When added plant material is " incubated " with soil in field conditions about two-thirds of the carbon is lost in the first three months; afterwards decomposition is much slower. A considerable proportion of the labelled carbon remains in forms that are more soluble in some reagents than the bulk of the soil organic matter, and is also decomposed preferentially in laboratory incubations. The microbial population is largely killed by partial " sterilisation " (heat, chloroform, radiation); when the soil is incubated after sterilising, a new microbial population builds up using the killed section of the first population as a substrate. But mineralisation of microbial carbon after the death of the organisms cannot be the only process liberating CO_2 after the soils are oven dried, otherwise the *percentage* of labelled carbon in the CO_2 evolved in successive incubations would be constant. Probably some of the unlabelled organic matter in the soil becomes less resistant on oven drying, is incorporated in microbial tissue during incubation and is released

later when the organisms decompose. On this basis about 2% of all the carbon of Plot 3 soil is in the " biomass " (organic matter in living organisms). About one-quarter of the labelled carbon remaining after one year in the field is in the biomass; this is equivalent to about one-tenth of the labelled plant carbon originally added. If all the parts of the biomass in the soil decompose at the same rate, its half-life is 2–3 years, to be compared with a half-life for soil organic matter as a whole perhaps ten times longer. (Jenkinson.)

Carbon monoxide evolved from soil

A mixture of CO_2 and CO was evolved from soil refluxed with 6N-HCl; Broadbalk Plot 2B soil evolved 8% of its organic carbon as CO_2 and 0·4% as CO during 3 hours refluxing. The carbon monoxide may be produced when α-hydroxy, or α-keto acids present in soil organic matter decompose. (Jenkinson.)

Field and Laboratory Experiments with Fertilisers

Alternative nitrogen fertilisers for spring barley

Four experiments on Chalk soils and one at Rothamsted compared urea and calcium nitrate with ammonium sulphate for barley. When the fertilisers were broadcast on the seedbed, urea and ammonium sulphate gave similar yields, but calcium nitrate gave more. When combine-drilled with the seed, ammonium sulphate was best, probably because it damaged early growth least. At centres where the barley was sown late in dry weather all fertilisers checked growth considerably and lowered yields; urea killed some of the plants and lowered yield most. The check to growth was less when the fertilisers were placed 1 inch to the side of the seed; gains from side-placement were greatest with urea and least with ammonium sulphate. With crops sown early in moist soil, combine-drilling gave better early growth and often better yields at harvest than side-placing. With crops sown later in dry weather, side-placement lessened early damage and gave better yields than did combine-drilling.

Side-placement requires a special drill or modifying an existing

Table 1

Average yields of barley given by three forms of nitrogen fertilisers in five experiments in 1961

(cwt. of grain/acre at 15% moisture content)

Yield without nitrogen, 20·8

	Ammonium sulphate	Calcium nitrate	Urea
0·35 cwt. N/acre			
Broadcast	26·9	27·9	26·6
Combine-drilled... ...	28·3	27·9	26·8
Side-placed	28·8	27·5	28·4
0·70 cwt. N/acre			
Broadcast	30·1	33·0	30·9
Combine-drilled... ...	30·3	31·1	29·6
Side-placed	30·3	32·0	33·1

combine-drill. The average gains from side-placement over combine-drilling, or seedbed broadcasting, were not enough to justify the extra cost of the special drill when either ammonium sulphate or calcium nitrate was used. But the experiments suggested that urea gives maximum yields of barley safely only when side-placed; the average gain from side-placement, about 2 cwt. grain/acre, would quickly pay for the extra equipment. However, most barley receives either ammonium or nitrate salts, so at present, side-placement is unlikely to have much general application. (Widdowson and Penny.)

Plant counts and samples were taken from the Rothamsted experiment 5 weeks after sowing. Urea was the only fertiliser that decreased plant numbers by more than 10% of the numbers growing on plots without N fertiliser; there was no damage with broadcast urea, serious damage with combine-drilled urea and some damage, though less serious, with side-placed urea. 0·7 cwt. N/acre as urea caused more damage than the half dressing. Samples taken 5 weeks after sowing were heavier with ammonium sulphate, however applied, than where no N had been given. At this stage calcium nitrate gave a smaller " yield " than ammonium sulphate for each method of application, and where the nitrate was combine-drilled, " yields " were 20% less than with no N. Urea also gave smaller plants than ammonium sulphate, was particularly damaging when combine-drilled and the dry matter produced was only half of that on plots without N fertiliser. (Gasser.)

Losses of ammonia from urea and from ammonium sulphate

In laboratory experiments urea and ammonium sulphate were either broadcast on the soil surface or mixed with a layer of soil 3 cm. deep, at rates equivalent to 100 lb. N/acre. One soil was a flinty loam containing 25% $CaCO_3$, the other had 75% $CaCO_3$. About 10% of the added nitrogen was lost to air drawn over the soil when the fertilisers were spread on the surface, about 5% was lost when they were mixed with the top-soil. With surface broadcasting losses were greater from ammonium sulphate, but after mixing the fertilisers with soil, more ammonia was lost from urea. On average nearly twice as much ammonia was lost from the very calcareous soil as was lost from the flinty loam. Increasing the temperature of the experiment from 5° to 25° slowed the rate of loss from the highly calcareous soil slightly, but doubled the loss from the flinty soil.

Other laboratory experiments measured losses of ammonia from urea supplied in different physical forms to different soils. Whether applied as pellets, crystals or solutions mattered little, but soil type was more important; the least loss (2% of the N added) was from a flinty loam, and the most (9%) was from a poor sandy soil. (Gasser.)

Effects of urea on germination

The damage to germination by urea, often shown in the field, was studied in pots under glass, and in the open using bottomless boxes filled with a range of soils. Germination of kale in pots was

slightly decreased by increasing rates of urea, but damage was not serious, even when urea equivalent to 300 lb. N/acre was applied. When harvested 18 days after sowing, 100 lb. N/acre gave maximum yields. Germination of wheat and barley in the boxes was irregular because of bad weather at sowing time in the first experiment sown in February. In the second, sown in April, germination was affected much more by the moisture contents imposed on the soils when the experiment was started than by the presence of urea. A third experiment was sown in June; high rates of urea decreased numbers, heights and weights of the plants, but the amount of damage again differed with different soils and with their moisture contents.

Damage by urea is thought to be caused by the ammonium carbonate and bicarbonate formed when the fertiliser decomposes in soil. These compounds may be dangerous because of high pH and/or free ammonia in the soil solution near to the fertiliser particles. Laboratory tests on the germination of kale, barley and wheat in presence of solutions of ammonium and potassium carbonates and bicarbonates showed that high concentrations (100–200 m.e./litre) of all these salts lowered germination; at the lower concentrations the ammonium salts caused most damage. Kale was damaged more than barley, and barley more than wheat. In the range of concentrations causing severe damage ammonium carbonate caused more than the bicarbonate. (Gasser.)

Tests of a concentrated fertiliser and of forms of nitrogen

An experiment at Rothamsted compared a concentrated fertiliser containing 20% N, 10% P_2O_5 and 10% K_2O with a mixture of ammonium sulphate, superphosphate and muriate of potash for kale, Italian ryegrass and barley, at rates supplying 1·0 and 2·0 cwt. N/acre for grass and kale, and 0·3 and 0·6 cwt. N/acre for barley. Differences between fertilisers were small; for barley and grass 20 : 10 : 10 was best, but for kale the mixture gave higher yields. The experiment also compared ammonium sulphate with ammonium nitrate, calcium nitrate and urea on the same crops and at the same rates of N. The high rate of ammonium sulphate and of urea checked establishment of Italian ryegrass, whereas 20 : 10 : 10 did not; ammonium nitrate and calcium nitrate checked growth only slightly. With kale the double doses of ammonium sulphate and calcium nitrate checked growth, whereas 20 : 10 : 10 did not; urea and ammonium nitrate checked growth slightly. With the single rate of N no crop was damaged. Calcium nitrate was best for kale at each level of manuring; for grass urea was worse than the other N fertilisers at each of two cuttings; all N fertilisers gave similar yields of barley. (Widdowson and Penny.)

Side-placement of concentrated fertiliser for barley

Three experiments compared broadcasting, combine-drilling and side-placing of a concentrated compound fertiliser containing 17% N, 11% P_2O_5 and 22% K_2O, at the rates needed to supply 0·3, 0·6 and 0·9 cwt. N/acre. The 1961 spring was dry, and combine-drilling checked growth considerably at two March-sown centres; placement checked growth less. At a February-sown centre combine-drilling

gave better growth. Placing the fertiliser 1 inch to the side of the seed gave more grain than did broadcasting; combine-drilling gave less grain than broadcasting with 0·6 cwt. N/acre at one centre and with 0·9 cwt. at two. (Widdowson and Penny.)

Methods of applying superphosphate for barley

The combine-drill modified for side-placement work with N fertilisers was used to test on barley different methods of applying 0·3, 0·6 and 0·9 cwt. P_2O_5/acre as superphosphate. Responses to P were small and 0·3 cwt. P_2O_5/acre was enough for full yields. Average yields at the three centres are stated below. Broadcasting the superphosphate either over the whole seedbed or in a restricted band immediately over the seed gave less grain than drilling the dressing. Side-placing gave slightly more barley than combine-drilling. (Widdowson and Penny.)

Yields of barley (cwt./acre)

Without phosphate	34·0
With broadcast super—	
over whole seedbed	36·7
in restricted band	37·2
With drilled super—	
combine-drilled	37·7
side-placed	38·2

Comparisons of solid fertilisers with solutions

A liquid N fertiliser (believed to be made mainly from urea) containing 20% N was compared with equivalent solid urea on Italian ryegrass. Both fertilisers were applied at several rates (the maximum 1·0 cwt. N/acre/cut) to grass 6–8 inches high. At 0·8 or 1·0 cwt. N/acre/cut, the liquid fertiliser scorched the grass, whereas solid urea did not. At each of three cuttings the solid fertiliser gave slightly more grass than the solution. The total gain from using the solid was not great; it was least (0·2 cwt. of dry matter/acre) with 0·2 cwt. N/acre/cut, and most (5·7 cwt. of dry matter) with 0·4 cwt. N/acre/cut.

A compound fertiliser in solution containing 14% N, 6% P_2O_5 and 8% K_2O was compared on kale with an equivalent mixture made from solid urea, superphosphate and muriate of potash. Both fertilisers were tested at 1·0 and 2·0 cwt. N/acre, and they were applied either to the seedbed before sowing or in mid-June over the crop, which then covered the ground completely. Solid fertiliser gave more kale than the solution in three of four comparisons; late dressings were better than seedbed dressings. There was no serious scorching. (Widdowson and Penny.)

Another experiment on Italian ryegrass compared ammonium sulphate, ammonium nitrate and sodium nitrate applied as solids and as solutions containing 5% N. All fertilisers gave significantly higher yields, and the grass took up significantly more N, when they were used as solids. This confirms earlier work (*Rep. Rothamst. exp. Sta.* for 1958, p. 47), and although the gains from using solid N fertilisers have been small, they have been consistent. (Nowakowski and Penny.)

Nitrogen and potassium fertilisers for Italian ryegrass

An experiment was started at Rothamsted in 1958 to measure the K fertiliser needed by grass manured with increasing levels of N. Yields from grass grown without NK fertiliser were compared with yields from 0·3, 0·6 and 0·9 cwt. N acre/cut (as " Nitro-Chalk "); tests were made of 0·0, 0·3 and 0·6 cwt. K_2O/acre/cut (as muriate of potash). Responses to superphosphate were measured only with heavy dressings of NK fertilisers. Table 2 summarises results over 4 years. Nitrogen gave large and consistent increases in yield when 0·3 or 0·6 cwt. N/acre/cut was used, but the extra N supplied by 0·9 cwt. N/acre/cut produced much less extra grass, and was probably not worth-while. Potassium had little effect on yield in 1958 and 1959. In spring 1960 the site was ploughed and resown, K dressings increased yields significantly at the first cutting, but later K had little effect. There were similar and very small increases in yield over the 4 years from both P and K fertilisers. Although K had little effect on yield, it greatly increased the percentage of K in the grass. Without K fertiliser the level of acid-soluble K in the surface soil fell seriously where N was applied; K levels in soil were maintained by using 0·3 cwt. K_2O acre/cut and were increased by giving 0·6 cwt. K_2O acre/cut, even though the grass took up much more K than was supplied by the fertiliser.

TABLE 2

Results of an experiment with N and K fertilisers on Italian ryegrass at Rothamsted, 1958–61

Treatments (all dressings are per acre for one cut)	Total yield of dry grass in 1958–1961 (cwt./acre)	Total uptake of K by grass in 1958–1961 (cwt./acre)	Acid-soluble K in surface soil in August 1961 (mg. K/100 g.)
Without N or K fertiliser ...	99	2·9	8·0
0·3 cwt. N plus:			
No K	227	6·2	5·2
0·3 cwt. K_2O ...	227	7·1	8·6
0·6 cwt. K_2O ...	229	7·3	18·0
0·6 cwt. N plus:			
No K	290	7·7	5·1
0·3 cwt. K_2O ...	297	9·0	7·9
0·6 cwt. K_2O ...	303	9·8	12·2
0·9 cwt. N plus:			
No K	312	8·1	4·6
0·3 cwt. K_2O ...	315	9·4	7·6
0·6 cwt. K_2O ...	324	10·8	13·5

The surprising feature of this experiment was that the soil could supply so much potassium over the four years, for the average withdrawal was about 2 cwt. K/acre/year with the heavier rates of N manuring. There was no indication that the rate of release of K fell off in the later years, although acid-soluble K in the soil became very low (Table 2). The small response to K dressings where heavy nitrogen was used (about 12 cwt./acre of dry matter in the four years) was not enough to pay for the fertiliser. On this soil no K manuring was needed to obtain full benefit from heavy N dressings, but this involved depleting soil K reserves. If the aim is to maintain soil K

status, the analyses in Table 2 show that 0·3 cwt. K_2O/acre/cut is enough even when the grass receives 0·6 or 0·9 cwt. N/acre for each cut. (Widdowson, Penny and Williams.)

The effect of previous cropping with grass on yield of following wheat

Three levels of N fertiliser were tested on pure swards of cocksfoot, meadow fescue, perennial ryegrass and timothy grown from 1958 to 1960; the produce was cut and removed and the results were summarised in last year's Report. After ploughing the grasses, spring wheat was sown in 1961 to measure the residues of the N fertilisers given and also the effects of fresh N and K fertilisers. Potassium had little effect on yield of wheat, even on plots where the grass had received 0·6 cwt. N/acre/cut and where the surface soil contained little K soluble in dilute acid. Wheat grown after grass dressed with N yielded more than wheat after grass without N. After ryegrass and meadow fescue, the wheat yielded better than after cocksfoot or timothy. (Widdowson and Penny.)

Grazed reference plots

A long-term experiment to test the effects of fertilisers on grazed grassland was started at Rothamsted in 1959 on an old parkland sward with little clover; the area had been limed, but the soil contained little soluble P or K. Grazing by sheep and beef cattle was unrestricted. Ammonium sulphate and calcium nitrate are compared, both applied in four equal dressings every second month through spring and summer; superphosphate and muriate of potash are applied as single winter dressings. Fertilisers have changed the sward but only slowly. Clover was suppressed by nitrogen (1·0 or 2·0 cwt. N/acre in the year), but grew freely when it was omitted. In 1961 the annual total N dressings were increased to 1·5 and 3·0 cwt. N/acre, and dry matter production was estimated in each two-monthly period by using cages to protect the grass from grazing. PK fertilisers increased yields, but when N was also used yields were nearly doubled; the higher rate of N gave no more grass than the lower rate. Ammonium sulphate scorched the grass and checked growth; calcium nitrate did not. Patches of grass died where 3·0 cwt. N/acre was applied as ammonium sulphate during the year. Sampling in October 1961 showed that ammonium sulphate soon made the surface soil acid; with the high rate of N as ammonium sulphate the pH was 5·4, with calcium nitrate 7·3; plots that had received no N had unchanged pH values (6.7). Lime will be applied in future where ammonium sulphate is given. (Widdowson and Penny.)

Effects of nitrogen fertilisers on the forms of soluble nitrogen and soluble carbohydrates in grass

Italian ryegrass was grown in a field experiment testing ammonium sulphate and sodium nitrate each applied at 0·5 and 1·0 cwt. N/acre. The fertilisers were applied to the established grass on 4 July, sampling began 10 days later and was repeated three times at 10-day intervals. Table 3 gives results from the first and

last samplings. The amounts of water-soluble nitrogen fractions in the grass were similar to those measured previously (*Rep. Rothamst. exp. Sta.* for 1960, p. 54). The N fertilisers decreased the total amounts of water-soluble carbohydrates in the grass considerably, causing small changes in glucose, fructose and sucrose, but a very large decrease in fructosan. The ratios of fructosan : soluble N and of total soluble carbohydrates : soluble N were both decreased by increasing amounts of nitrogen fertiliser; the ratios were particularly narrow in the earlier stages of growth. These ratios may have some bearing on the nutritional value of grass and on the digestive disorders sometimes reported when ruminants eat grass dressed heavily with nitrogen; they may also be important in silage-making. (Nowakowski.)

TABLE 3

Soluble carbohydrates and soluble nitrogen in Italian ryegrass treated with N fertilisers

		Sampling		Sampling	
		First	Last	First	Last
		Fructosan		Total soluble carbohydrate	
	lb. N/acre	% in dry matter			
Without N	0	4·1	16·0	11·8	27·4
Sodium nitrate ...	56	0·6	8·6	5·4	18·9
	112	1·2	5·9	8·9	15·4
Ammonium sulphate ...	56	0·8	9·6	7·0	20·8
	112	0·6	5·5	7·2	16·4
		Ratio of			
		Fructosan / Soluble-N		Total soluble carbohydrate / Soluble-N	
Without N	0	14·5	93·3	42	159
Sodium nitrate ...	56	0·5	20·7	4	46
	112	0·9	6·5	7	17
Ammonium sulphate ...	56	0·9	44·2	8	96
	112	0·5	5·8	6	17

SITKA SPRUCE ON ARABLE LAND AT WOBURN

Twenty-five square-yard plots sown with Sitka spruce were added to a series of " reference plots " on farm crops and soft fruit started on old arable land in Stackyard Field at Woburn in 1960 (*Rep. Rothamst. exp. Sta.* for 1960, p. 55). Seedlings on unmanured plots were only 0·3 inch high at the end of the season, but those with full inorganic manuring (NPK + Mg) averaged 1·3 inches. Phosphorus and, to a less degree, nitrogen were responsible for this large increase—P increased the size nearly four times and N increased it by a third. This spectacular response to P on conifer seedlings is of special interest on a site where the other agricultural and horticultural crops responded only little to P. Neither K nor Mg had any effect on the size of seedlings, though slight yellowing typical of Mg-deficiency developed on the " no Mg " plots late in the season. Formalin (a " partial sterilant ") added to plots with full inorganic manuring increased height by 60%; whatever its mode of action,

formalin cannot, on this land, have controlled a population of soil pathogens specific to conifers, which have not grown on this site for at least 100 years. (Benzian.)

Nitrogen in Soils

Fixed ammonium

Ammonium in soil that cannot be exchanged by KCl solution is said to be " fixed ". Fixation depends on the kinds of clay minerals present; vermiculite fixes NH_4 very strongly, most montmorillonites less strongly and illite is intermediate. Methods that are said to measure fixed NH_4 have been developed, but little is known of its physico-chemical properties. It is not known whether fixed NH_4 is truly non-exchangeable; should it be very slowly exchangeable, increasing fixed NH_4 could add to the reserves of slowly available N in soils. The exchange properties of fixed NH_4 are therefore being examined by using $^{15}NH_4$, which makes the measurements very sensitive.

Hydrobiotite (intermediate in composition and properties between biotite and vermiculite) fixed much NH_4 and was used in early experiments. The fixation and exchange capacities of the mineral were saturated by repeated treatment with N-NH_4Cl at 70°. The product was then shaken with 0·01M-NH_4Cl, containing up to 30% of ^{15}N, for varying times; the NH_4 and ^{15}N in the solution, in the fraction exchangeable with KCl, and remaining in the mineral were then measured. Unexpectedly, only one-half to three-quarters of the NH_4 exchanged by KCl was exchangeable with labelled NH_4, and the reason is being investigated. The fraction of fixed NH_4 which exchanged was approximately proportional to the square root of the time of contact. This suggests that the process governing the rate of exchange is diffusion of NH_4^+ in the layers of the mineral and that the exchange of fixed NH_4 differs in degree, rather than in kind, from exchange of Ca^{++} or Mg^{++}, which are not much fixed. The work is now being continued with hydrobiotite from which potassium in the mineral structure has been removed by sodium tetraphenyl boron. (Oliver and Newman.)

Up to 80% of the potassium in micaceous minerals can be extracted by sodium tetraphenyl boron ($NaBPh_4$), which forms an insoluble compound with K. The hydrobiotite used here contained nearly 4% K; it was treated for a week with N-NaCl containing $NaBPh_4$ to see if NH_4-fixation capacity would increase when K was removed. The solid remaining, a mixture of mineral and $KBPh_4$, was saturated with N-NH_4Cl and the $KBPh_4$ dissolved away by washing with 70% aqueous acetone containing NH_4Cl, to prevent the dissolved K from the $KBPh_4$ re-entering the mineral lattice. In this way 98% of the K in the mineral was removed. The original hydrobiotite had 1·03 m.e. K/g., after extraction it had only 0·02 m.e. K/g.; but its capacity for fixing ammonium had increased from 0·59 to 1·29 m.e./g. The difference between the K extracted (1·01 m.e./g.) and the increase in fixed NH_4 (0·70 m.e./g.) was accounted for by Na^+ (0·35 m.e./g.), which was trapped as the lattice contracted on the NH_4^+. These results show that ammonium and potassium fixation are similar in character and mutually dependent. (Newman.)

Fixation of nitrogen by soils incubated with straw

Fixation of N was not detected when moist soil was incubated with straw, whether or not oxygen was present. However, when the soil was waterlogged fixation occurred (for example, 5 g. soil with 0·7 g. straw and 15 ml. of water fixed nearly 2 mg. of N in 56 days) provided air was present above the incubated mixture, but not when the air was replaced by nitrogen. Hence fixation depended on the incubation proceeding with a zone where oxygen was deficient but not absent. (Barrow and Jenkinson.)

Phosphate in Soils

The effects of ammonium sulphate and sodium nitrate on solubility of soil phosphate

Twelve calcareous soils (with $\frac{1}{2}$ $3\frac{1}{2}$% $CaCO_3$) from the Rothamsted and Saxmundham Classical Experiments were used, five of which had received superphosphate every year for over 60 years and seven had never received phosphate fertilisers. In an experiment with ryegrass growing in pots differences between yields from equal amounts of N as ammonium sulphate and from sodium nitrate increased as the experiment continued, and $(NH_4)_2SO_4$ gave more grass. The poor soils that had never received P fertiliser gave better yields with $(NH_4)_2SO_4$ than with $NaNO_3$ from the beginning of the experiment, and at the end yields were twice those with $NaNO_3$. Grass grown on the five soils that had received superphosphate regularly did not respond to extra phosphate, and yields from the two forms of N were similar until the fourth cut, when $(NH_4)_2SO_4$ gave larger yields. These differences were because $(NH_4)_2SO_4$ released more phosphate than did $NaNO_3$ from calcareous soils, and they were much greater with Saxmundham Chalky-Boulder-Clays than with calcareous Clay-with-Flints from Rothamsted. After 20 weeks in the pot experiment, soils treated with $NaNO_3$ had unchanged $CaCO_3$ contents, but those treated with $(NH_4)_2SO_4$ had lost 0·8% of their initial $CaCO_3$. To get such a loss of $CaCO_3$ in the field would require giving 2 cwt./acre of $(NH_4)_2SO_4$ every year for 80 years; similarly, this treatment would be needed to release from $CaCO_3$ particles the amount of P released in the greenhouse experiment, and in any one year the amount released by $(NH_4)_2SO_4$ to field crops would be trivial.

A further pot experiment used soils from a field experiment on Carboniferous Limestone done by Mr. R. D. Russell (National Agricultural Advisory Service). Where $(NH_4)_2SO_4$ had been given in the field experiment yields of grass, P uptakes and A values in the pot experiment were all significantly greater with soils that received 2 cwt./acre of $(NH_4)_2SO_4$ for 5 years in the field experiment than from soils receiving no N fertiliser. (Mattingly and Barbara Close.)

Laboratory measurements of isotopically exchangeable phosphorus (P_e) in the Rothamsted and Saxmundham soils used in these pot experiments, before and after cropping, showed that more P was removed by the grass receiving either form of nitrogen than was accounted for by the fall in P_e. The release of non-exchangeable P

from $CaCO_3$ particles dissolved by heavy doses of $(NH_4)_2SO_4$ (350 mg. of N 100 g. of soil in the course of the experiment) is to be expected, as most native calcium carbonates contain phosphorus, but the release of non-exchangeable P when $NaNO_3$ was given has no ready explanation. The dressing of sodium in the pot experiment (25 m.e. Na^+ 100 g. soil) is much larger than would be supplied by normal fertiliser dressings for arable crops, and it is not certain that using $NaNO_3$ would affect P release in the field. (Mattingly and Talibudeen.)

Ion-exchange resins in soil phosphate studies

A mixture of anion- and cation-exchange resins saturated with chloride and sodium extracted only the rapidly exchanging component of the total isotopically exchangeable phosphorus from very acid soils (pH values of 3·6–4·6). The extraction was complete in 2 weeks. In less-acid soils (pH values 5·6–6·6) the resins removed some of the " slow " isotopically exchangeable P and the rapidly exchanging fraction was completely extracted in ½–1 day. In less-acid soils containing residues of P fertilisers, isotopically exchangeable phosphate was more labile and therefore easily removed by ion exchangers; only half of the total exchangeable P was removed by resins from the very acid soils, but 80% or more was extracted from less-acid soils. Total isotopically exchangeable P was well correlated with the P extracted by the resin mixture.

The resin extracted more calcium from less acid soils, though more slowly, than from the more acid soils. The aluminium extracted from all the soils increased exponentially with time. The total amount of Ca + Al extracted (in milli-equivalents) was only slightly greater in the near-neutral soils than in the very acid soils, suggesting that the two metals together occupied the greater part of the total base-exchange capacity of the soils. Higher exchangeable Al in the more acid soils was associated with lower mobility of isotopically exchangeable P. There was no stoicheometric relationship between either the total P extracted or its rapidly and slowly extracted components, and the Fe and Al removed by cation-exchange resin; this suggests that the resin mixture cannot distinguish between phosphates of stoicheometric compositions and the other sources of Fe and Al that may be present.

The processes that control the speed at which resins extract phosphate may involve the movement of ions from the inside of a soil particle to its surface, and then across the thin layer of liquid that is the diffuse electrical double layer surrounding the particle. Graphical analyses show that several first-order reactions probably occur simultaneously. With soils above pH 5 a single " bulk " diffusion process accounted adequately for *all* the data, and in more acid soils this process accounted for most of the extracted phosphate. (Vaidyanathan and Talibudeen.)

The processes of isotopic exchange in acid soils

Soils supplied by Mr. J. W. Blood from an experiment at N.A.A.S. Headquarters, at Shardlow, Derbyshire, where fertilisers and levels of acidity are tested, show that residues of phosphate fertilisers re-

maining in soil are more mobile at higher pH's. On soils of pH 3·6–5·6 only about one-half or two-thirds of the total isotopically exchangeable P is rapidly exchangeable. While the rapidly exchanging fraction is being removed, a single first-order reaction equation fits the data, suggesting that " film " diffusion through the electrical double layer controls the rate. Afterwards diffusion of phosphate from *inside* the soil particles governs the speed at which exchangeable P is liberated. (Talibudeen and Vaidyanathan.)

Phosphorus soluble in 0·01M-$CaCl_2$ solution in equilibrium with soils

There are good theoretical reasons for using the concentrations of P in 0·1*M*-$CaCl_2$ solutions in equilibrium with soils as measures of P that is immediately useful to crops. Some factors that may affect the concentrations were studied. Common agricultural factors, such as recent dressings of fertilisers or the presence of decomposing straw, had little effect. Values were reproducible and not affected by details of laboratory technique, such as methods of shaking. The standard time of contact of soil and solution adopted was 15 minutes, longer times had only small effects. Usually 20 g. of soil and 100 ml. of solution were used; P-concentrations with twice as much or half as much soil were a little greater or smaller. P-values were increased by grinding soils finely and were affected by the way the soils were dried.

Possible seasonal variations were investigated by sampling several sites with contrasted histories at both Rothamsted and Woburn at monthly intervals through the year. P-concentrations in $CaCl_2$ solutions were always less with fresh than with air-dried samples. Values in heavy soils at Rothamsted were remarkably constant and showed no seasonal variation on each site, except they were increased where FYM or phosphate fertilisers were added during the year. The P-concentrations were also constant in the poorer of the light soils at Woburn, but in very rich Woburn soils P-values fell slightly during the year. None of the changes that occurred during the season altered the classification of P-status for practical purposes.

In the Rothamsted soils that have received FYM each year P-concentrations in $CaCl_2$ solutions were greater than the values in soil of plots treated annually with superphosphate that has supplied about as much P as was supplied by FYM. Where both FYM and superphosphate have been applied, P-values were greater than the sums of values on plots receiving FYM and superphosphate separately; a given amount of P applied to soil retains a higher solubility when FYM is regularly applied. (Blakemore and Cooke.)

Phosphorus Deficiency in Barley

The plots of the old Rotation Experiment in Agdell Field which received superphosphate every fourth year from 1848 to 1948 grew good barley in 1959 and 1960. Fresh dressings of superphosphate did not increase yields on plots containing the most P-residues, but there were small increases on plots containing less. The crops appeared normal throughout both seasons. In 1961, however, the older leaves of young barley plants growing on Plot 1 with only a

moderate amount of P-residues, and with no new dressings of superphosphate, became yellow when the plants were about 3 inches high. Where fresh superphosphate was broadcast on parts of this plot the plants were normal and were 6 inches high by the beginning of May, when the yellow plants had stopped growing. Table 4 shows analyses of plants with different intensity of yellowing taken from plots with different P fertiliser treatments.

TABLE 4

Analyses and appearance of barley grown on Agdell Field in 1961

P-residues from Rotation Experiment 1848–1948	Recent superphosphate treatment 1959–60	1961	Colour of plants	N	P	K
				% in dry matter		
Plot 1 medium residues	P	P	Green	4·4	0·30	4·6
	O	P		4·0	0·25	4·2
	P	O	Yellow	3·2	0·12	3·0
	O	O	Very yellow	3·1	0·11	3·2
Plot 3 largest residues	P	P	Green	4·2	0·27	4·6
	O	P		4·2	0·30	4·4
	P	O		3·9	0·30	4·7
	O	O		4·2	0·22	4·5
Plot 5 no residues	P	P	Green	4·1	0·24	4·0
	O	P		4·7	0·30	4·8
	P	O	Purple tinge	3·9	0·16	4·1
	O	O		3·9	0·11	4·0

From experience of young barley on the Rothamsted and Woburn Farms, the yellowing on Agdell would be diagnosed as a deficiency of N or K (% N and % K both being about 3), or both. As NK basal fertiliser was applied to the seedbed, however, the low values were not because N and K were lacking in the soil, but because P was inadequate in the soil of Plot 1. The dressings of P given in 1961 not only increased the P-contents of the plants but also increased the N and K contents to levels at which there was no yellowing. The level of the old P-residues, adequate to prevent yellowing in 1959 and 1960, was inadequate in 1961, as were residues from superphosphate applied in 1959 and 1960. Plot 3, which has much larger old P-residues, was free from yellowing. Plants on Plot 5, the unmanured plot of the old Rotation Experiment, with a very low level of soil P showed the purpling usual for deficiency, and they contained only 0·1% P.

A. Sorteberg (1960, *Landbrukshögskolens Institutt for jordkultur, Saertrykk* nr. 46) investigated similar spring-time yellowing of barley in Norway. Yellow plants had small and poorly developed roots, and an average K content of 2·6%. Pore space in the soil was less, and the ratio of air to water much less, where the barley was yellow. The yellow symptoms were attributed to poor root development limiting uptake of K. No physical measurements were made on Agdell soils, but seedbeds in 1961 were poor after a wet and mild winter, and were worse on Plot 1 than on Plot 5. This difference may account for the differences in colour symptoms and in uptakes of N and K where phosphate in the soil was low in these two plots. The yellow colours on Agdell disappeared as the

weather became drier and warmer, but yields were affected, and about 10 cwt. grain/acre were lost where the crop had been yellow.

This experience shows how the effects on barley of a poor seedbed may be lessened by a fresh dressing of superphosphate where the soil has only moderate levels of soluble P. (Warren and Johnston.)

Soil Potassium

Measuring "available" potassium

Exchangeable potassium measurements are useful in classifying the K-status of soils that are either "very low" or "very high", but are much less useful in assessing "medium" soils. The K removed by grass in short-term experiments from about fifty soils was poorly correlated with exchangeable-K for soils containing 10–20 mg. K/100 g. soil. But K uptakes by the grass were closely related to values for $pK-\frac{1}{2}pCa$ (measured at equilibrium with $0{\cdot}01M$-$CaCl_2$ solutions) and to the free-energy changes calculated for the replacement of K by Ca. (Arnold and Barbara Close.)

Values for $pK-\frac{1}{2}pCa$ measured in equilibrium $CaCl_2$ solutions before and after adding K (as KCl) are being used to develop a way of estimating the amount of K-fertiliser needed by crops. $pK-\frac{1}{2}pCa$ is almost linearly related to the amounts of K added, and the values do not generally depend on whether the soils are fresh or air-dried. (Arnold.)

The amounts of K were measured in the equilibrium $CaCl_2$ solutions used to study seasonal changes in P values (p. 55). Many samples were taken from the site of the Barnfield Experiment fallowed in 1961; the values were quite constant through the year on plots receiving no K fertiliser or FYM and where the soil was very low in K. On other plots the values were increased by the usual annual dressings of FYM and of K fertilisers, but there was no other seasonal change. In sampled fields growing crops in 1961 K values fell in spring and summer; they rose again after mid-summer in fields under grass or cereals, but under sugar beet they remained low until autumn. These differences may be connected with lengths of growing seasons and with cycles of root growth. (Blakemore and Cooke.)

Release of non-exchangeable potassium

Much information about the release of non-exchangeable-K has been obtained by continued cropping in the greenhouse. In many illite-rich English clays K releases are five to ten times more than the fall in exchangeable K. A few soils released much K because they contained glauconite (identified by I. Stephen, Pedology Department). The K-releasing power of the soils used was related to soil series identified by the Soil Survey. (Arnold and Barbara Close.)

Potassium–magnesium relationships

Field experiments are being done at both Rothamsted and Woburn to test potassium (as K_2SO_4) and magnesium (as $MgSO_4$) on ryegrass. (Magnesium in crops and soils has been determined

by A. Weir, Pedology Department.) These fertilisers affected crop composition more on Woburn sandy loam than on clay-loam at Rothamsted. Table 5 gives analyses for the first harvest in the second year of the sward at Rothamsted and for the first cut of

TABLE 5

Effects of K *and* Mg *dressings on the ratios of* K : Mg *in Italian ryegrass*

(all quantities of K and Mg were in equivalents)

	Mg applied (lb./acre)			
	0	58	0	58
	Rothamsted		Woburn	
K applied (lb./acre)	Ratios of K/Mg			
0	5·8	4·4	6·4	4·2
95	8·7	6·6	9·0	6·6
190	9·6	7·9	11·4	8·4

newly sown grass at Woburn. At Rothamsted % Mg in the dry grass ranged from 0·09 to 0·15, and at Woburn from 0·12 to 0·22. Potassium dressings increased yield of grass slightly at Rothamsted and more at Woburn. Magnesium had no effect on yields at Rothamsted and gave a small but significant increase at Woburn. (Arnold and Penny.)

The Value of Residues of PK Fertilisers in Soils

Continuous Barley site at Woburn

Further estimates of the values of old residues of P and K fertilisers were obtained from a micro-plot experiment on the site of the Permanent Barley Experiment on Stackyard Field at Woburn, where the "classical" treatments started in 1876 and stopped in 1927. Table 6 shows the increase in yields of three crops caused by the P and K residues in the soil. (Warren, Johnston and Penny.)

TABLE 6

Increases in yields of barley, potatoes and sugar beet caused by residues of P *and* K *fertilisers in soils of the Classical sites at Woburn*

	Barley (grain) (cwt./acre)	Potatoes (tons/acre)	Sugar beet (sugar) (cwt./acre)
	Increases from P residues		
1960	6	1	—
1961	4	2	9
	Increases from K residues		
1960	0	3	—
1961	0	3·5	13

Effects of methods of applying P *and* K *fertilisers on comparisons of new dressings with old residues in soil*

Micro-plot experiments on Agdell Field at Rothamsted and on Stackyard Field at Woburn in 1959–60 showed that the way fertilisers are applied to poor land may control their effectiveness. Estimates of the values of P and K residues obtained by comparing

yields of crops grown on land with residues, with yields from land without residues, were lower than estimates of residual values derived from the response curves given by fresh dressings of fertilisers. Although the new fertiliser dressings were considered enough for maximum yields, the highest rate of fertiliser on plots without PK residues often gave yields below those on the plots with residues. The new fertiliser dressings were broadcast just before preparing barley and sugar-beet seedbeds; for potatoes the fertilisers were broadcast between ridges immediately before hand-planting at Rothamsted and on the flat before machine-planting at Woburn. As the two estimates of the values of the PK residues may differ because of differences in the positions in the soil of the residues and the new dressings, comparisons of broadcast applications with ploughed-in dressings were started in 1961. With the high rate of fresh superphosphate (1·5 cwt. P_2O_5 per acre on Agdell, 1·0 cwt. P_2O_5 per acre on Stackyard Field), ploughing-in gave better yields than broadcasting for barley and sugar beet; method of application did not affect yields of potatoes. With the half rate of P the results were variable, ploughing-in P was sometimes less effective than broadcasting. Potassium dressings were tested only at Woburn, where differences between methods of application were all small. (Warren, Johnston and Penny.)

Soil Magnesium

All our staff who have worked with magnesium in crops and soils have benefited by using the new equipment for direct-reading spectrographic-determination of magnesium, built and operated by A. Weir of the Pedology Department (*Rep. Rothamst. exp. Sta.* for 1960, p. 81).

A group of English and Welsh soils is being cropped exhaustively in glasshouse pot experiments; the soils contain 0·2–1·0% total Mg, mostly in the clay. Mg exchanged by ammonium acetate varies from 40 to 240 lb. Mg/acre (2–12 mg. Mg/100 g. of soil). Although in glasshouse cropping ryegrass may contain up to 0·7% Mg in dry matter, yield is unaffected by lack of Mg until it has less than 0·1% Mg, and crops have been grown with only 0·04% Mg. Different plants remove different amounts of Mg, radishes three or four times as much as grass.

After 6 months continuous cropping, ryegrass has not removed more Mg than was originally present in exchangeable form. The amounts of Mg taken up are not related to the original exchangeable Mg values. Uptakes decline steadily after 2–3 months of cropping, suggesting that release of non-exchangeable Mg is less important than the corresponding release of non-exchangeable K. Probably measurements of exchangeable Mg fail to predict uptake because the other bases present interfere. At constant base saturation, Mg : Ca ratios in grass are proportional to the ratios of exchangeable Mg : Ca in soil. High K levels depress Mg uptakes by grass seriously, especially in soils rich in Mg.

Ion activity ratios such as $\frac{\sqrt{Mg}}{K}$ and $\sqrt{\frac{Mg}{Ca}}$, calculated from

measurements in dilute electrolyte solutions in equilibrium with soils, may help to explain cation uptake by plants, but their use is complicated by changes in the base status of soils during cropping. (Salmon and Arnold.)

Cation–Anion Relationships in Crop Nutrition

The uptake of ions by plants is influenced by the presence of other ions, uptake usually being decreased by ions of similar charge and increased by those of opposite charge. Samples of Italian ryegrass (*Lolium multiflorum*) from many places in Britain were analysed to see if the ratio of total cations : total anions was constant. The cations measured were: Na^+, K^+, Ca^{++} and Mg^{++}; the anions were NO_3^- (assumed responsible for the uptake of N), $H_2PO_4^-$, SO_4^{--} and Cl^-. Silicon was also measured. Forty-five individual samples grown on different soils in five seasons with varied fertiliser treatments, and cut at different stages of growth, were examined. Total anions and total cations each ranged widely (100 g. of dry grass contained from 80 to 170 m.e. of total cations and from 130 to 500 m.e.) (including silicon) and 100–400 m.e. (omitting silicon) of total anions. In the whole group of samples total cations were closely correlated ($r = 0{\cdot}59$*** with silicon and $r = 0{\cdot}69$*** without silicon) with total anions.

Twenty ryegrass samples from an experiment at Rothamsted in 1960 were analysed. They had been cut at the same stage, but had received different fertiliser treatments. Total cation contents (from 130 to 180 m.e./100 g. dry grass) were well-correlated ($r = 0{\cdot}77$***) with total anions (240 to 350 m.e./100 g. of dry grass) when silicon was included. The correlation ($r = 0{\cdot}94$***) between total cations and total anions (180–280 m.e./100 g. of dry grass) was even better when silicon was excluded.

These relationships are being examined in more detail by micro-plot field experiments at Rothamsted and Woburn. On each farm one experiment on ryegrass and one on kale tested the effect on ion uptake of varying those ions, excluding micro-nutrients, which may be important in crop nutrition. Preliminary data on the grass show the expected relationships between cations: increased uptake of Na, K and Mg depresses uptake of Ca; where K uptake increases Na decreases, and increasing Mg uptake decreases K. Increasing NO_3^- uptake has the greatest effect; it depresses Cl^- uptake, but increases uptake of all other ions.

As much of the NH_4^+ was converted to NO_3^- before it was absorbed, its effect resembled that of NO_3^- but was less pronounced. Cl^- depressed NO_3^- and SO_4^{--} uptakes, and increasing SO_4^{--} decreased Cl^- uptake. (Cunningham.)

W. Dijkshoorn (*Netherlands J. agric. Sci.* 1957, **5**, 233) stated that anion contents of ryegrass (omitting silicon) do not exceed 400 m.e./100 g. of dry matter and that the corresponding maximum total cation content is 200 m.e. In the work described above the total cation and anion contents do not exceed these values when silicon is excluded. Pot experiments are now being done to see if there are values for total ions in grass that are not normally exceeded. (Karim and Cunningham.)

Surface Areas of Roots

Imperfect agreement between laboratory measurements of "available" nutrients and crop performance is often caused by assuming that the whole of the ploughed layer of soil is "swept" by roots. This is rarely true with annual crops; the proportion of the soil from which nutrients are taken depends on soil structure and permeability as well as on the root characteristics of particular crops. Attempts are now being made to estimate *in situ* the surface areas of roots of growing plants by electrical measurements. The amounts of maize roots growing in soils, sand cultures and nutrient culture solutions were estimated by measuring capacities and resistances. (Walker.)

Micronutrients

Interactions of phosphates and manganese salts

When superphosphate is applied for crops two interactions with soil manganese are possible. Some workers have reported that superphosphate increases the availability of soil Mn and that, when superphosphate is drilled in contact with seed on Mn-deficient soils, mixing a small quantity of Mn salt with the super is more effective in controlling Mn-deficiency than applying the dressings separately. At the other extreme some acid soils contain much soluble Mn which is toxic to plants, and toxicity is decreased by soluble phosphates which precipitate Mn. The effects of Mn/P ratios, and of pH, on the precipitation of manganous phosphate were investigated by measuring the pH values at which precipitates started to form when KOH was added to mixtures of $MnSO_4$ and H_3PO_4. With Mn : P ratios of 0·1 and 1·0, Mn began to precipitate at pH 5–6 and precipitated completely above pH 6·5. With a Mn : P ratio of 10 some Mn remained in solution until pH 8·2; both Mn and P were redissolved at pH values above 10. With manganese concentrations of 10^{-2} and $10^{-3}M$ and an initial Mn : P ratio of 1 the composition of precipitates was $Mn(OH)(PO_4)_{0·65}$. At a Mn : P ratio of 0·1 the precipitates corresponded to $Mn(OH)_{10}PO_4$ and $Mn(OH)(PO_4)$ for the above Mn concentrations. With Mn : P ratios of 10 ill-defined compounds were precipitated at the Mn concentrations used; more basic phosphates were generally precipitated at the higher pH's used. (Heintze.)

The effects of various treatments on exchangeable manganese

Prolonged air-drying, or steam sterilising, of soils generally increases readily soluble Mn. In laboratory experiments soluble Mn was not increased after treating soils with chloroform or mixed γ radiation. Drying soils at 80° for 24 hours increased exchangeable Mn, and steaming did so even more. As exchangeable manganese was unaffected by treatments that eliminated microbiological action without heating, its increase by heat probably depends on a chemical process. (Heintze.)

Total micronutrients in soils

The total amounts of manganese, copper, molybdenum and zinc were determined in seventeen soils ranging from heavy clays to

light sandy loams. The sites used had known histories; six were pastures in Yugoslavia. The work is being done to give information on total reserves of these micronutrients in different soils, and to show whether different treatments, continued over long periods on similar soils, have affected reserves. Two methods of extracting micronutrients from soils were compared—fusion with sodium carbonate and digestion with hot fuming nitric acid. H. H. Le Riche (Soil Survey of England and Wales) measured the micronutrients by separate spectrochemical methods and also determined the amounts remaining in the silica residues left after extracting chemically.

Manganese. On average more than 90% of the Mn extracted by fusing with Na_2CO_3 was also removed by digesting with fuming HNO_3; acid was less effective on soils with much sand. The spectrochemical results for total Mn were often higher than those from both chemical methods.

Copper. Usually fuming HNO_3 extracted about 75% as much Cu as was extracted by the fusion method. The acid method also gave more variable results with Cu than with Mn, and the lowest values for Cu extracted by HNO_3 were with soils rich in sand. The spectrochemical results followed those obtained by HNO_3 and were lower than those by the fusion method.

Molybdenum. Variable proportions of the total Mo in the soils used were extracted by fuming HNO_3, and fusing with Na_2CO_3 was much more reliable. The proportion of the total Mo extracted by HNO_3 was highest with soils that had been under grass for a long time and with soils that had received organic manures for many years.

Zinc. The amounts of Zn extracted by fuming HNO_3 agreed well with those extracted by fusing with Na_2CO_3. Nitric acid seems quite satisfactory for determining Zn, and is preferred, as it is much quicker than the fusion process.

Total potassium and iron were also determined in the extracts. From 5 to 40% of the total K in the soils (determined by the fusion method) was extracted by fuming HNO_3. The amount of K extracted by acid was related to the previous treatment of the soil, and was most from land given organic manures regularly or land under permanent grass. Most of the iron extracted by fusion was also extracted by digesting with HNO_3; the acid method was accurate enough for most work on the soils used. (Savic and Williams.)

Natural Radioactivity in Soils

The β-radioactivity of 35 British soils was measured (accurate to $\pm 1{\cdot}3\%$) using total counting time of 30 minutes for each soil. The γ-radioactivity spectra of these soils is now being explored. Natural radioactivity will then be related to the total potassium, uranium and thorium in the soils. (Talibudeen and Yamada.)

Experimental Methods

Determining nitrate-nitrogen in soil and plant extracts

For the last 6 years titanous sulphate was used here as the reducing agent when determining nitrate-nitrogen in soil and plant extracts (J. M. Bremner & K. Shaw, *J. agric. Sci.* 1955, **46**, 320–328). This reagent is now difficult to obtain in the United Kingdom, and supplies may stop completely. As an alternative, the old well-known Zn–Cu couple method was tested. Williams (*J. chem. Soc.* 1881, **39**, 100–111) was the first to apply the reducing action of a Zn–Cu couple in determining nitrates in water; in the 1880s Warington used Williams' method to determine nitrates in soils from the Classical Experiments at Rothamsted. The method (E. J. Russell, *J. agric. Sci.* 1914, **6**, 18–57) continued to be used here until about 1920, when it was replaced by the Devardas' alloy method. Reduction by the Zn–Cu couple was slow, and 2 days at 25–30° were allowed to convert nitrate to ammonium.

The Institute of Water Engineers has adopted an improved Zn–Cu couple method, in which nitrate is reduced much more quickly (*Approved Methods for Physical and Chemical Examination of Water*—Joint Committee Report, Institute of Water Engineers, London, 3rd ed., 1960). Granulated Zn is used to prepare the couple and up to 1,000 μg. NO_3-N can be reduced either at room temperature for 2 hours or at 37° for 1 hour. In our tests of the Zn–Cu couple method this year Zn powder was used to make the couple; CuO was also added because this increased the vigour of reaction. Because nitrate is reduced at the point where hydrogen is evolved, the rate of reduction will depend on the speed at which the solution of nitrate passes over the solid Zn–Cu couple, or the speed at which the couple moves through the solution. The increased vigour of the reaction, obtained by using Zn powder for preparing the Zn–Cu couple and by adding CuO, reduced 100 μg. NO_3-N in ½ hour at room temperature. Our results agree well with those using the titanous sulphate method. Further tests are being made of the most suitable amounts of Zn–Cu couple, of CuO and of the minimum time for complete reduction. (d'Arifat and Warren.)

Total sulphur in plant materials

Existing rapid methods for measuring sulphur in plant material are unreliable, and a new method using indirect flame photometry was developed. Sulphur in plants is first oxidised to sulphate by digesting with fuming nitric acid and then ashing with magnesium nitrate at 450°. Sulphate is precipitated as the barium salt, washed, dried and then dissolved in ammonium EDTA solution. The barium in this solution is measured by a flame photometer. The method is quick, reliable and accurate. (Cunningham.)

Mass spectrometer

The sensitivity of the mass spectrometer was increased twenty-fold by fitting a vibrating condenser amplifier for measuring very small D.C. currents. With this modification much smaller samples can be analysed (the optimum with the old arrangement was 0·4 mg.

N), and quantitative corrections can be made for air contamination. In 1961 300 samples were analysed. (Newman.)

Using ryegrass in pot experiments

Perennial ryegrass has been used as a test crop in greenhouse pot experiments for more than 10 years. It is adequate for most problems that can be dealt with by pot experiments and grows well on a wide range of soils. Recently the range of very acid soils used was extended, and the growth of ryegrass was independent of pH between 3·6 and 8·0 (measured in 0·01*M*-$CaCl_2$ solution) provided adequate phosphate was given. A single soil maintained in the field at pH 3·2 gave much lower yields; other soils of pH values below 4·5 gave constant yields for the first four cuts, afterwards yields fell by about one-tenth. (Mattingly and Barbara Close.)

PEDOLOGY DEPARTMENT

A. Muir

J. H. Rayner attended a colloquium on Clay Mineral Genesis and Synthesis held in Paris. A. Muir visited India on behalf of UNESCO to consider the setting up of a Central Institute for Pedology and Soil Mechanics in relation to existing institutes. Mr. C. B. Wells (Commonwealth Scientific and Industrial Research Organisation) returned to Australia. Dr. M. Covadonga Rodriguez Pascual completed her study of swelling properties of soils with R. Greene-Kelly and has joined the Soils Department in Oxford. Mr. Ismail Tunckale (Istanbul University) is working with both the Soil Survey and the Pedology Department.

The following visitors came to gain experience in X-ray techniques: Professor R. Lounsbury, Purdue University, Indiana; Dr. A. Lapa, University of Oporto; Mr. I. Babiker, University of Khartoum; Mr. D. Carroll, University of Oxford; Mr. E. Robinson, University of Queensland; Mr. P. Watson, University College of Rhodesia and Nyasaland. Their training occupied much time and detracted from the ordinary work of the department.

G. Brown edited, on behalf of the Mineralogical Society, the second edition of *The X-ray identification and crystal structures of clay minerals*, which has now been published and should be as successful internationally as the first edition.

Soil Formation

Sols lessivés (*gray-brown podzolic soils*)

In the definition of this group of soils, referred to as brown earths, Robinson allowed some mechanical translocation of clay. The profiles of such soils have an increased clay content in the subsoil and in Europe are known as *sols lessivés*. We have not attempted to characterise such soils in Britain in any detail, but if they are to be recognised here as elsewhere as an international group it is obvious that soils chosen for comparison should be developed on homogeneous parent materials of which loess-like drifts are the most suitable. The Soil Survey and Pedology Department were invited to co-operate in the detailed study of profiles of *lessivé* type derived from " brickearth ". The samples were collected by Mr. P. Askew (Wye College), and the results recorded below are the joint work of the Pedology Department and the Soil Survey.

The site, at Kennington, Kent, is 165 feet above sea-level on a very slightly sloping terrace. The average rainfall is about 29 inches per annum; the average maximum and minimum temperatures (° F.) in winter are 53·8 and 22·0 and in summer 83·4 and 43·6 respectively. The vegetation is mainly of oak with beech, sycamore, holly and elder; ivy is the only ground flora. Drainage of both site and profile is satisfactory.

The profile consists of thin ($\frac{1}{4}$ inch) F layers overlying a very

dark brown, finely granular loam A_{11} horizon (2 inches) which changes abruptly to a brown, structureless, very friable, loam to silt loam A_{12} horizon (12 inches) that merges into a pale brown, structureless, silt loam A_2 horizon about 6 inches thick. A transitional B_1 horizon (8 inches) separates the A horizons from the B_2 horizon, which is over 36 inches thick, and is characterised by dark-brown and reddish-brown colours, prismatic structure and a slightly finer texture than the upper layers. Between 66 and 72 inches this merges into C horizon material of yellowish-brown, structureless silt loam, which persists to about 96 inches and shows gley features along old root channels.

Thin sections were examined, and the disposition of the oriented clay indicates that it has been removed from the two upper mineral layers and accumulated in maximum amounts between about 35 and 50 inches. Evidence of clay deposition in voids is visible even at 96 inches. The maximum frequency of secondary iron concretions at about 22 inches suggests not only segregation at a single level but also movement of iron down the profile. Darker segregations of iron and manganese oxides become prominent near the base of the profile, and their deposition may be associated with the higher pH values and the presence of small calcite grains at 66–84 inches. The rarity of glauconite, muscovite, feldspars and calcite in the upper layers might suggest a different parent material from that

Sample depth (in.)	2½–13½	13½–19	19–27	30–36	39–45	66–72	78–84
Horizon	A_{12}	A_2	B_1	B_2	B_2	C_1	C_1
Moisture 100–105° C. ...	2·28	2·05	2·10	2·69	2·80	3·07	2·89
Mechanical Fractions							
600–2,000 μ	0·9	1·0	1·2	0·1	0·1	0·1	0·1
200– 600 μ	2·7	2·3	2·6	0·8	0·6	1·7	2·1
60– 200 μ	6·7	6·3	6·0	5·9	5·9	9·0	6·6
20– 60 μ	45·7	45·3	45·0	41·2	38·2	45·5	47·0
6– 20 μ	20·6	20·0	20·3	22·5	20·1	19·4	16·4
2– 6 μ	5·1	5·4	4·5	5·5	6·6	5·0	4·3
1– 2 μ	2·4	3·9	5·4	2·8	5·3	2·6	2·3
<1 μ	13·6	14·2	15·5	21·2	24·6	19·3	18·6
% $CaCO_3$						0·2	0·3
Dissolved R_2O_3 (included in <2 μ)	0·3	0·2	0·2	0·1	0·1	0·1	0·1
Loss on ignition, % ...	5·4	3·6	3·4	3·5	3·4	2·9	2·7
Organic carbon, % C. ...	2·26	0·97	0·72	0·27	0·20	0·10	0·12
pH in water (1 : 2·5) ...	4·2	4·4	4·5	5·1	5·2	7·5	7·8
Exchangeable Ca	0·70	0·65	1·60	6·09	6·22		
m.e./100 g. Mg	0·09	0·11	0·28	1·59	1·46		
,, K	0·04	0·05	0·10	0·13	0·12		
,, Na	0·03	0·03	0·11	0·26	0·31		
Total ...	0·9	0·8	2·1	8·1	8·1		
,, H+	15·8	11·5	10·5	7·2	6·6		
C.E.C. (by addition) ...	16·7	12·3	12·6	15·3	14·7		
Total Bases (Jackson) ...	2·5	3·3	4·5	10·3	10·6		
Soluble Fe_2O_3, % (KCl–EDTA)	0·67	0·76	0·74	0·59	0·46	0·50	0·59
Soluble Al_2O_3, % (KCl–EDTA)	0·25	0·26	0·26	0·20	0·18	0·16	0·19
Clay Analysis							
SiO_2/R_2O_3	2·64	2·63	2·58	2·73	2·72	2·74	2·69
SiO_2/Fe_2O_3	9·47	10·70	10·15	10·00	9·61	10·65	10·10
SiO_2/Al_2O_3	3·70	3·49	3·47	3·76	3·79	3·68	3·65

below, but it is more probable that they have been weathered out and the decomposition products removed from higher levels by leaching. X-ray analysis of the clay minerals reveals that vermiculite–montmorillonite are dominant below 2·5 inches, with mica dominant in the top mineral soil. This is a common feature in some soils and suggests that the potash released by the vegetation is adsorbed and fixed by the clay.

The table presenting analytical data of selected layers shows that the mechanical analyses support the idea that the profile is homogeneous, for there is no striking difference between horizons in the amount of any fraction except of the clay. This increases greatly at about 30 inches and maintains similar high levels to about 66 inches, below which it decreases. The rise in the amount of clay, combined with the thin-section observations, confirms that clay has been mechanically transferred into the B horizon. That little chemical breakdown has occurred is revealed by the ratios of silica to sesquioxides which, except for slight decreases in SiO_2/Fe_2O_3 between 19 and 45 inches, are almost constant down the profile. Thin sections confirm the segregation of iron at these levels. As might be expected, the exchangeable bases increase with the increased clay content of the B horizon, in which the exchangeable hydrogen decreases from the higher values, associated with lower pH values, in the upper layers.

All the evidence suggests that this profile falls into the class of " sols bruns lessivés " or " gray-brown podzolic soils " developed on silty material which becomes slightly calcareous at depth. (Bascomb, Du Feu, Rudeforth, Stephen.)

Mineralogy

Clay mineralogy

The normal crystallographic work was hampered by the record number of visiting workers, all of whom required instruction in X-ray techniques, and most of whom examined their own material to incorporate the results in theses. (Brown.)

A total of 214 samples from home and overseas were analysed for clay minerals. The common presence of palygorskite in soils from the Middle East has previously been reported. This mineral was again found in some Persian soils. Unless it is present in large amounts, it is more simply detected by the electron microscope than by X-rays. (Du Feu and Brown.)

Physical Chemistry of Soil Minerals

Surface studies

It is a common observation that clay soils of similar clay contents differ greatly in drainage characteristics, which are evidently correlated with the development of structure in the subsoil. An examination of the factors responsible was started with a study of a range of $(Ca, Mg)^{2+}$ saturated subsoils with clay contents about 50%, but with widely differing nitrogen specific surfaces (27–103 $m.^2/g.$ external surface). The physical properties of these soils are being compared; so far the British Standard plastic and liquid limits,

suction curves and shrinkage characteristics have been measured. The plasticity index (liquid limit–plastic limit) was nearly independent of the specific surface, in agreement with the results of Odell, Thornburn and McKenzie (*Proc. Soil Sci. Soc. Amer.* 1960, **24**, 297–300), who found that it could be highly correlated with clay content and less so with mineral composition of the clay, silt percentage, exchange capacity and carbon content. The maximum shrinkage, i.e., the difference between the liquid limit and shrinkage limit, was remarkably constant for the remoulded samples, although the field soils had very different characteristics. For example, gilgaied tropical black earths from Australia have exceptionally high specific surfaces (relative to clay content) and have great shrinkage with detrimental effects on foundations, fences, and telegraph posts. In this connection, Stephen, Bellis and Muir (*J. Soil Sci.*, 1956, **7**, 1–9) investigated a puff and shelf phenomenon in soils of the Athi plain (Kenya) and concluded, despite evidence of termite activity, that the soils were gilgai. The specific surface of the soils was 150 $m.^2/g.$ (for 100% clay), the highest specific surface yet measured on a soil. The natural inference is that the soils would be gilgai if the conditions were suitable.

The effect of removing free iron oxides and organic matter on the specific surfaces of selected soils was investigated. Removing organic matter increased the specific surface, whereas removing iron oxides usually slightly decreased it. (Rodriguez and Greene-Kelly.)

Apparatus

A high-speed differential thermal analysis apparatus was made to the design of Foldvari-Volg and Klibursky. It is manually operated during the fifteen-minute run, and the differential temperature is recorded photographically. The apparatus has excellent resolving power; it has been demonstrated for the first time that the 50–200° endotherm of illites has the same double-peak formation (depending on the exchange cation) as montmorillonite.

A vacuum thermobalance using a silica spring was built. The products of decomposition can be condensed in traps or the apparatus filled with a particular gas depending on the information required.

Both these new instruments will be used to study soil minerals. (Greene-Kelly.)

Clay mineral synthesis

The series of experiments on the rate of transformation of silica–alumina gel to kaolin described last year was continued at the lowest of the temperatures used before (180°), but allowing longer reaction times. At 180° the time for half conversion is at least six weeks.

Brindley and De Kimpe (*Nature, Lond.* 1961, **190**, 254) claimed to have prepared kaolin at 150° in one to three weeks from gibbsite and "Ludox" silica sol or ethyl silicate in *N*/10-HCl. Similar experiments in a furnace built by G. C. Dibley, to heat six sealed glass tubes to this temperature while turning them end-over-end,

gave only a small yield of kaolin. The difference is explained by the wrong estimates made of reaction tube temperature, for De Kimpe (private communication) now states that the temperature for complete transformation should be 165–175°. In the first experiment done here the maximum tube temperature was 160°, and running the furnace 10° higher gave 33% conversion of gibbsite and silica sol to kaolin in 8 days and 75% conversion in 16 days. This is a very much faster reaction than that using silica alumina gel.

Advantage was taken of the technique developed to prepare kaolin from silica–alumina gel in which deuterium would replace most of the hydrogen. The silica alumina gel was dried at 500° and treated in the furnace with 99·9% D_2O at 300°. The infra-red absorption of the product was measured by Dr. V. C. Farmer (Macaulay Institute) as part of his work on the assignment of infra-red bands in sheet silicate structures. He found that replacement was nearly complete and the sample contained very little hydrogen. (Rayner.)

Spectrochemistry

Trace elements in soil separates

Studies of the manner in which trace metals are combined in soils showed they are held in one or more of the following ways: (1) as water-soluble or exchangeable ions; (2) as integral constituents of primary and secondary minerals (including association with the sesquioxides); (3) as a non-exchangeable part of the organic matter.

Two well-drained brown earths (Charity and Hatfield series) were used, from which the samples were taken from the surface horizons enriched in organic matter and from the clay-enriched horizons. When the soils were dispersed in dilute ammonia solution and the fractions analysed the sums of the trace elements Ba, Co, Cr, Cu, Ni, Ti, V and Zr in the sands, silts and clays very nearly equalled the totals in the untreated soils. This indicated that only small proportions of the elements occurred in the soils as water-soluble or exchangeable ions. Dispersion with ammonia was incomplete, for much of the sand- and silt-size fractions obviously consisted of clay-size material cemented with iron and aluminium oxides. To remove these oxides before mechanical analysis, Tamm's oxalate method, as modified by A. S. de Endredy, was used, in which the extraction is done under ultra-violet irradiation. For trace-element work the method has the great advantage that the oxalate can be highly purified and is readily removable, so that both the extracted sesquioxides and the cleaned sands, silts and clays can be readily analysed. Unfortunately, part of the soil organic matter is also extracted, and it has not yet been possible to estimate directly the trace elements associated with it.

The experiments show that less than 1% of the silica of the soil was extracted, from which it was concluded that the treatment does not cause appreciable breakdown of the silicate minerals. Approximately 60% of the total iron and 10% of the total aluminium in the soil were removed as sesquioxides, and, as repeated extractions removed no more, the remaining iron and aluminium were assumed

to be constituents of the silicate minerals. The sesquioxide extract contained more than 90% of the Co, Cu and Mn, approximately 60% of the Ni, Pb and V, but less than 10% of the Ba, Cr, Ga, Sr, Ti, Y and Zr. Of the elements remaining in the soil after treatment, Co, Cu, Ga, Ni, Pb and V were greatly concentrated in the clay fraction. (Le Riche and Weir.)

Spectrophotometric determination of magnesium

As mentioned in last year's Report, a spectrophotometer for determining magnesium by the porous-cup technique was built in the laboratory by G. C. Dibley and R. Farrow. The machine is a copy of one at the Macaulay Institute, and we acknowledge the very generous help given by Drs. R. L. Mitchell, R. O. Scott, A. Ure and others at the Institute. In twelve months more than 3,000 determinations in soils and plants were made for the Soil Survey and the Chemistry Department. The apparatus gives a precision of $\pm 2\%$ per determination at an even temperature, but tedious recalibrations with standards are often needed in the winter when the laboratory temperature fluctuates widely. Attempts to stabilise the temperature have so far failed.

The rate of production of porous-cup electrodes was increased by using a machine for cutting carbon rods. It was built by the Workshop from plans drawn by B. Edwards from photographs of a similar machine at the Macaulay Institute. The new machine gives a smooth and reproducible cut and is quiet and dust-free in operation. It will handle all the carbon rods for spectrographic work. (Weir.)

The many soil and plant samples analysed for semi-major and trace elements included some for members of the department, other workers at Rothamsted, the Forestry Commission and the Colonial Office. Discoloured and stunted seedlings of Sitka Spruce and Lawson's Cypress growing near wire netting surrounding the seedbeds contained abnormally high zinc.

Samples of forest soils sent by the North Borneo Department of Agriculture contained high levels of total Co, Cr and Ni. (Burnett.)

Soil Chemistry

Determination of total sulphur in soils

The combustion method for determining total sulphur (*Rep. Rothamst. exp. Sta.* for 1960, p. 82) was adapted to the micro-scale appropriate for soils. The soil is heated with V_2O_5 in a current of nitrogen and oxidation of volatile organic compounds is completed by contact with hot CuO. The combustion products are passed over hot metallic copper to reduce oxides of nitrogen and to convert SO_3 to SO_2, which is absorbed in a solution of sodium tetrachloromercurate and determined colorimetrically with *p*-rosaniline.

Methods based on the reduction of sulphate to sulphide are subject to interference from copper, but this appears to be without influence in the present method. 100 p.p.m. S may be determined accurately in the presence of a tenfold excess of Cl^-, PO_4^{3-}, NH_4^+ or NO_3^-.

Combustion with V_2O_5 also appears to offer a more rapid and convenient method than distillation with HBr/Br_2 for separating Se from soils. Preliminary results were encouraging, and the method is being further investigated.

Copper fixation by organic matter

The formation of a surface organic mat in an orchard with a long history of heavy spraying with copper fungicides was described in earlier Reports. The mat is 1–2 inches thick, and a bulked sample had a total copper content of 1,870 p.p.m. The following figures relate to the mineral soil immediately below the mat, and show that the copper content falls off very sharply:

0–½ inch 130 p.p.m. Cu
½–2 inches 70 p.p.m. Cu
2–5 inches 45 p.p.m. Cu

About 5% of the total copper was extractable from the mat as collected, at pH 7, and some 30% was removed at pH 3; these values decreased when the mat was air-dried. The material can take up considerably more copper, but this is completely removed on extraction at pH 3, so that the copper-fixing capacity of the mat is saturated.

In an investigation of the effect of cultivation on the release of copper from the mat, aerobic incubation for one month did not change the amount of copper extracted at pH 7, but the amount removed at pH 3 increased by about 200 p.p.m. Incubation for a further period of one month slightly decreased the amount of acid-extractable copper, but the value remained higher than for the original material. The addition of subsoil, nitrogen and green manure slightly increased the amount of extractable copper, but in view of the low density of the mat, about 0·28 g. per cubic cm., it seems unlikely that ploughing it in would make the soil phytotoxic. Experiments to study this point are in progress.

More than half the copper contained in the mat is removed by extraction with a mixture of ethanol and benzene, and the copper thus extracted includes essentially all that removed by ammonium acetate at pH 3. An artificially copper-saturated phragmites peat behaved similarly. As peat waxes are acidic in nature, the solvent-soluble copper is probably combined with these compounds and is present as a metallic soap. (Bloomfield and Pruden.)

Apparatus

Electron probe

The preliminary work on the electron probe reached a stage which justified the design and development of a practical model. It has been decided to accept an electron beam of 3 μ until the need for a smaller one becomes apparent; the larger beam is likely to be more stable and permit steadier operating conditions. Geiger-counter equipment and X-ray crystal plates were obtained, and the apparatus is being constructed to enable samples to be examined by one of several techniques—emission, absorption or microscopy. The specimen chamber is designed to take 3 specimens, 18 standards and 18

X-ray transmission targets, which can be interchanged, without releasing the vacuum, from outside the chamber. The specimen can be moved under the beam in the horizontal plane in steps of 5 μ, enabling any part of the specimen of $\frac{3}{4}$ inch diameter to be examined. The vacuum system was modified to increase pumping speed and to improve the vacuum in the radiation chamber.

An evaporating plant was built for making X-ray transmission targets for use with the electron probe. It is designed to enable targets to be made by evaporating material on to "Melinex" sheet, and the target material is of the order of 1 μ thick.

Several prototypes of Cartesian divers were made for C. L. Bascomb, as well as a tank to determine the density of clay suspensions by means of a liquid density gradient.

The quartz crystal monochromator was completely redesigned to make adjustments easier and more effective, and also to enable the monochromator to be used with an ordinary 9-cm. powder camera. (Dibley.)

SOIL MICROBIOLOGY DEPARTMENT

P. S. Nutman

R. M. Jackson left in June for two years' secondment to the Soil Bureau, Wellington, New Zealand, to work on soil fungi. G. Lim was awarded the Ph.D. degree of the University of London and returned to Singapore in April. B. Mosse spent eight weeks at the University of Pisa as an O.E.E.C. Research Fellow. Under the auspices of the Royal Society, Prof. E. N. Mishoustin, Corresponding Member of the U.S.S.R. Academy of Sciences, made Rothamsted a centre from which he visited microbiological laboratories in the United Kingdom over a period of two months. Through the International Association for the Exchange of Students for Technical Experience, Dr. H. Klaus of the Institute of Microbiology, Göttingen, spent six weeks working with N. Walker on the microbiological effects of drying soil. At the invitation of the United States Department of Agriculture, Clover and Range Division, Beltsville, and the Legume Inoculant Manufacturers' Association, P. S. Nutman visited and lectured at State Colleges in the U.S.A.

Work was started in collaboration with the Departments of Plant Pathology and Biochemistry on the moulding of hay. Because of requests for information from the Advisory Service and elsewhere, experiments were initiated on the effect of vacuum treatment on inoculation of legume seed.

Distribution of nitrogen fixers and nitrifiers in soil

The distribution of nitrogen fixers and nitrifiers in soil was further studied. A series of samples taken from Park Grass in the spring showed nitrifiers to be present except in the very acid plots. The unlimed halves of Plot 3 (no manure, pH 5·5) and Plot 9 (ammonium sulphate, pH 4) contained none, but the limed halves of the same plots contained many nitrifiers, as did the whole of Plot 14 (sodium nitrate, pH of unlimed half 6, of limed half 7).

Four plots on Broadbalk (Nos. 3, 5, 7 and 10) all contained very many nitrifying bacteria during summer; more than 6,000 ammonia-oxidisers per gram were counted from Section III, carrying the first crop after fallow. Section I, fallow, had fewer. *Azotobacter* was also more numerous on Section III than on Section I.

The grass end of Broadbalk Wilderness contains many nitrifiers, and many *Azotobacter*; the wood end also has many nitrifiers, but few *Azotobacter*. Other woodland soils had few or none of either. Two samples from Morven (Argyll), under oak and pine, had no *Azotobacter*, very few Clostridia and no nitrifiers; but an arable sample from the same place had about 1,000 Clostridia per gram, and many nitrifiers. Pine wood samples from Delamere Forest (Cheshire) had no *Azotobacter*, no nitrifiers and very few Clostridia. A series of beech-wood soils from the Chilterns were similar, except

for a calcareous mull, which had moderate numbers of nitrifiers and nitrogen fixers.

Further counts on the long-term Bare Fallow on Highfield showed no *Azotobacter* in this soil and that Clostridia and cellulose-decomposers have become very few, whereas the numbers of nitrifiers are well maintained. (Meiklejohn.)

Methods of counting Azotobacter

The effect of the following factors on the spread-plate method of counting *Azotobacter* was examined: (1) the method of preparing the soil suspension; (2) the time agar plates were dried before adding the suspension to the surface; (3) the concentration of phosphate in the agar medium. Neither grinding the soil in a mortar before suspending in distilled water nor mixing the suspension in a M.S.E. top-macerator increased the count compared with simple shaking, but shaking the soil suspension with glass beads for only 3 minutes increased it by 80–100%; longer shaking with beads had no further effect. Adding dispersing agents ("Nonidet", "Tween 80") to the soil suspension, varying the length of time the soil was held in suspension before plating or the type of suspending fluid (tap water, distilled water or physiological saline) and the time of shaking (up to 30 minutes) had no significant effect on the count of *Azotobacter*.

Concentrations of phosphate in the medium greater than 2 g./l depressed the count when the phosphate was added separately to the autoclaved medium. Surface drying altered the concentration of salts in the medium, and drying appeared to affect *Azotobacter* colonies growing on mannitol more than those grown on glucose medium. Tests of media containing different energy sources confirmed the superiority of glucose and sucrose over mannitol. Satisfactory results were obtained with the dilution-tube method when $CaCO_3$ was added to the tubes as a buffer. (Brown, Burlingham and Jackson.)

Natural distribution of Azotobacter *in plant rhizospheres*

The distribution of *Azotobacter* was studied in the rhizospheres of 17 crops grown in 13 different soils in the field and glasshouse. *Azotobacter* were usually few in both rhizosphere and soil. In the field *Azotobacter* was present in only 1 of 60 rhizosphere samples from soil below pH 6·5, but in 168 of 177 samples from soils above pH 6·5; of these only 86 had more *Azotobacter* in the rhizosphere than the corresponding soil sample. In the glasshouse experiments (soil pH above 6·5) *Azotobacter* was in the rhizospheres of 201 samples, and more numerous in 149 of these than in the soil samples. The presence or absence of a rhizosphere effect seems to depend on plant species, age of plant at sampling and soil type. *Azotobacter* was never recovered from serial root washings, indicating that it was present in the rhizosphere only and not on the root surface. (Brown and Burlingham.)

Factors affecting establishment of inoculated Azotobacter *in the rhizosphere*

Results of inoculating seed, roots or soil in field and greenhouse experiments showed that large populations of *Azotobacter* could be

established and maintained in the rhizosphere. Some of the factors affecting establishment were examined. Wheat seed, inoculated with the same volume of 2-, 7- or 14-day-old cultures containing $1{\cdot}5 \times 10^9$ viable cells per ml., were sown immediately after inoculation or one day later. The *Azotobacter* on the seed were counted immediately after spraying, after storing the seed for one day and in the rhizosphere after 3 weeks. Recovery of *Azotobacter* from seed and its establishment in the rhizosphere depended on age of culture, and was greatest with the 14-day-old culture. A delay of 1 day between inoculation and sowing had little effect on establishment, although the seed recovery for the 2-day-old culture decreased more than 1,000 times. *Azotobacter* establishment was not significantly affected by soil moisture over the range normally found in the field (10–20% water holding capacity). (Brown and Burlingham.)

Effect of Azotobacter *inoculation on crop yields*

Five field experiments, two with wheat and one each with barley, potatoes and beet, showed no significant increases in yield from inoculating seed with *Azotobacter*. Earlier field trials (*Rep. Rothamst. exp. Sta.* for 1960, p. 91) reported sporadic and significant effects on yield which were always associated with good establishment of *Azotobacter* in the crop rhizosphere. In the 1961 field trials *Azotobacter* failed to become established in three experiments because of low or marginal pH, and in the remaining two experiments (on wheat and sugar beet) establishment was poor. The beet experiment gave a 6·6% increase in yield of roots, but this was not significant.

Eight pot experiments in the greenhouse with six different crops all gave a small total increase in yield resulting from *Azotobacter* inoculation. None of these total increases was individually significant at the 5% level. However, as shown in Table 1, four experiments produced significant effects of inoculation in some treatments. (Brown, Burlingham and Jackson.)

TABLE 1

Crop	Method of inoculation	Increase in total yield from inoculation (not significant)	Treatment	Partial yields	Significant increase
Wheat	Seed	+ 5·6%	+ NP	Ear wt.	+21%
Tomato	Root	+11·0%	J. I. compost	Green tomatoes	+41%
Spinach	Root	+18·1%	−N, 60% W.H.C.	Top wt.	+13%
Carrot	Seed + soil	+ 1·5%	−N, seed inoc.	Root wt.	+45%

Studies on Nitrosomonas

In a search for faster-growing strains or species of *Nitrosomonas*, three further strains were isolated in pure culture from different soils or activated sludge. Altogether five such strains have now been examined and shown to differ in morphological and physiological characteristics. These organisms, however, all have roughly the same growth rate in pure culture, namely a doubling time of 10–12 hours; washed organisms of the different strains all oxidise both ammonia and hydroxylamine to nitrous acid.

Attempts to obtain pure components from the cytochrome fraction, which can be readily isolated from *Nitrosomonas* cells, have not yet succeeded, neither has a cell-free enzyme fraction able to oxidise ammonia yet been obtained. (Walker.)

Decomposition of simazine, stilboestrol and toluene in soil

To study the persistence in soil of simazine, a synthetic herbicide, and stilboestrol, a synthetic stilbene derivative with oestrogenic activity and used in agriculture, enrichment cultures were set up. Although there are some indications that these compounds can be biologically degraded, attempts to isolate pure cultures of organisms able to break them down have so far failed.

A knowledge of how toluene is degraded by bacterial action is important in relation to the fate of a methyl group when linked to an aromatic molecule. A soil bacterium has been isolated which grows readily, under certain conditions, in a simple salts solution containing either toluene, benzene or benzyl alcohol as sole carbon source. Toluene cultures produce a bright yellow, fluorescent, acidic pigment, which has been isolated in small quantity. The oxidation of various aromatic compounds by washed toluene-grown organisms was studied in Warburg respirometers. The pathway of the bacterial decomposition of toluene remains to be established. (Walker.)

Microbial population changes in self-heated hay

Changes in bacterial and fungal populations in self-heated hay were studied in connection with the Plant Pathology Department's programme on mouldy hay and Farmer's Lung disease. Wet and dry bales, 30% and 15% moisture content respectively, were made from hay of Great Field and sampled frequently during the summer. A stack of each type of hay was also built and studied in the same way.

At each sampling time a large sample was removed from bale or stack and a sub-sample taken for analysis of the wind-blown micro flora (Plant Pathology Department). Hay from a second sub-sample was cut into 2–3-cm. lengths, thoroughly mixed, and a 10-g. portion shaken mechanically with sterile water for 10 minutes to prepare a suspension for bacteriological analysis. (This same suspension was used by the Biochemistry and Plant Pathology Departments for pH determinations and some wind-tunnel experiments.) Serial dilutions were plated with nutrient agar and replicate plates incubated at 25°, 40° and 60°. Anaerobes and micro organisms able to grow in an acid lactobacilli medium were also counted. Some of the cut hay was used for chemical analysis and moisture determinations by the Biochemistry Department.

Dry bales reached a maximum temperature of only 27° 2 days after baling, and thereafter cooled to just below 20° for most of the 90-day sampling period. The numbers of bacteria growing at 25° and 40° tended to decline after reaching a peak coincident with the temperature peak. Fungi at 25° were fairly numerous, but few grew at 40°. No growth was found at 60° in the dilutions tested, and the populations of fungi and bacteria at lower incubation

temperatures were very mixed in species composition. This hay was sweet-smelling and remained in good condition throughout the experimental period.

In the wet bales a maximum temperature of 55° was recorded after 3–4 days, and thereafter the temperature slowly declined. Bacteria at 25° increased rapidly to a peak of $1{\cdot}9 \times 10^8$/g. dry wt. when the temperature was highest and then fell to $5{\cdot}5 \times 10^5$/g. after 15 days. Bacteria at 40° showed the same trend, although they were always fewer than at 25°. At the start thermophilic bacteria growing at 60° were few, but rose steadily from $6{\cdot}4 \times 10^3$/g. at 6 days to $1{\cdot}7 \times 10^7$/g. at 21 days. Fungi at 25° and 40° were numerous throughout. The hay was dusty with fungus spores and had an unpleasant irritating odour.

In the dry stack the character of the hay and the pattern of change in the microbial population resembled that of the dry bales. However, hay from the centre of the wet stack differed greatly from that in the wet bales. High temperature was maintained in this stack for a long period, and a maximum of 65° recorded. The hay was dark brown, and had a tobacco-like odour and an acid reaction. Bacterial populations at all three incubation temperatures remained at a high level until the 16th day, after which they fell sharply. Fungi at all incubation temperatures remained numerous throughout the period.

A second set of bales was made from hay cut from Great Knott I. The wet bales contained 35% moisture and reached a temperature of 60° three days after baling. Many bacteria and fungi were recorded at all incubation temperatures, and the hay developed an odour even more irritating than that of the wet bales from Great Field. In the dry bales from Great Knott (20% moisture content) microbial activity was greater than in the corresponding bales of hay from Great Field. Fungi growing at 25° and 40° were numerous, but in spite of this the hay was not obviously "mouldy" like the wet bales of both series. Actinomycetes were rare on the plates made from any of the hays tested, although plentiful when agar plates were inoculated on the surface with wind-blown dust from some hay samples by the Plant Pathology Department.

Anaerobes and organisms growing in the lactobacilli medium occurred in most samples, but were almost always few and showed no definite trends. Micro-organisms which appeared to predominate in some of the samples were isolated and cultivated for use in future laboratory experiments. (Skinner.)

Methane fermentations

Work on the isolation and cultivation of the methane-producing bacteria and on the behaviour of these bacteria in mixed culture with anaerobic cellulose-decomposing bacteria is continuing, and will be reported later. At the request of the Sports Turf Research Institute, the emanation of inflammable gas in quantity from cultivated land at Eckington in Derbyshire, where soil containing much pig manure had been dumped on to a badly drained soil, was investigated. Tests showed that methane was generated in the upper layers of the soil by fermentation of the abnormal amounts of

readily decomposable organic matter. The surface soil is being removed to restore the area to its former condition. (Skinner.)

Transformation studies on Rhizobium trifolii

Work on the transformation of symbiotic virulence (Ljunggren, *Rep. Rothamst. exp. Sta.* for 1960, p. 85) was extended to a study of the transformation of symbiotic effectiveness in nitrogen fixation. A bacteria-free preparation of deoxyribose nucleic acid (DNA) from a strain of clover nodule bacteria (Strain H.K.C.) which is quite ineffective in fixing nitrogen in red clover nodules was used successfully to transfer this property to a normal effective strain (Strain A). All such transformations in response in Strain A were to complete ineffectiveness; no intermediate forms were recovered. The efficiency of the transformation (in terms of proportion of altered cells) depends on the concentration of DNA and the length of time the recipient strain is grown in the donor DNA; the optima for these factors are being determined. The transforming activity of DNA preparations declines on storage at −20°. (Kleczkowska.)

Inheritance of resistance and ineffectiveness in red clover

A single family of red clover (late-flowering Montgomeryshire) selected for sparse nodulation, segregated two kinds of abnormal plants: (1) non-nodulating plants, and (2) plants that gave an ineffective response in nitrogen fixation with a normal effective strain of bacteria (Strain A); these abnormalities were investigated genetically.

The non-nodulating seedlings were weakly, and only two survived to the flowering stage. These were crossed together (133 florets cross-pollinated) but produced no seed. Sib crosses between nodulating and non-nodulating plants gave small families with a high proportion of abortive seeds (seed set, 19%; germination, 36%). Of the seeds which germinated 21 nodulated and 2 did not. Crosses among nodulating plants were more successful (seed set, 42%; germination, 70%). Two resistant plants appeared in the 143 seedlings examined; they were normal as seedlings, but neither survived to the flowering stage for further breeding work. This form of host resistance to nodule formation, which is clearly heritable, because resistance is otherwise very rare in red clover, differs from a previously described host resistance (*Heredity*, 3, 263, 1949) in that it is not simply inherited, and is not associated with a maternally transmitted component, but it is similar in its association with early lethal effects.

The ineffectively responding plants segregating in the same original family were recessive for a simply inherited factor, provisionally designated *n*. *n* homozygotes in segregating families formed the same number of nodules as their effective counterparts. Breeding experiments showed that the factor *n* was distinct from the ineffective host factors i_1 and *ie* previously described.

The ineffective response in *n* homozygotes was specific to bacterial Strain A. (Nutman.)

Inoculation of legume seed by vacuum treatment

Loneragan, Moye and Anderson (*Nature, Lond.* **192**, 526, 1961) report that alternate application of a vacuum and atmospheric pressure to legume seed at the time of inoculation with *Rhizobium* improves the survival of the inocula during later storage. To study this, lucerne and red clover seeds were inoculated with ^{32}P-labelled *Rhizobium* spp. with or without vacuum applications. The residual radioactivity, and hence the number of bacteria retained by the seeds after washing, was measured by Geiger-counting the sulphuric acid digests of the seeds. Lucerne seeds inoculated without vacuum treatment and washed three times carried 5×10^3 bacteria per seed for every 10^8 bacteria per ml. of inoculum; vacuum treatment increased uptake of bacteria by 90–120%. Further washing (up to twenty washes) removed 10–20% of the bacteria per wash. The percentage difference between bacterial numbers with and without vacuum treatment was much decreased by washing, and disappeared after twenty washes. Red clover seeds retained only one-fifth as many bacteria as did lucerne seeds.

The uptake by seeds of ^{32}P compounds in solution was studied with supernatant fluid from the centrifuged cultures used to produce ^{32}P-labelled *Rhizobium*. Here also, the vacuum treatment doubled the uptake of ^{32}P and washing removed it by 10–20% per wash.

The agricultural benefit which may result from such additional retention of *Rhizobium* by legume seed after vacuum treatment depends on the way in which the bacteria are distributed between seeds. This was investigated by treating lucerne seeds with ^{32}P-labelled *Rhizobium*, with and without vacuum treatment, washing three times, drying and distributing the seeds over the surface of X-ray film. The developed film was examined for dark spots coincident with the original positions of the seeds. 100 seeds produced only 6–11 dark spots, with or without the vacuum treatment. The effect of vacuum treatment was merely to intensify 3–5 of the spots about four-fold (estimated visually). A similar picture was given by seeds treated with the labelled culture fluid. A duplicate sample of the seeds used had a germination percentage of 95.

These results suggest that vacuum treatment does not increase bacterial impregnation of normal good seed of lucerne or clover and cannot be recommended in practice. Samples of commercially produced vacuum-inoculated seed of both lucerne and red clover were examined; nodule bacteria per seed were few and could not be detected at all in some samples. (Cooper.)

The microbial transfer of bound nitrogen from agar and other sources to plants

Growth and nitrogen content of *Trifolium parviflorum* on nitrogen-deficient agar slopes were increased by inoculation with a *Pseudomonas* sp. (*Rep. Rothamst. exp. Sta.* for 1960, p. 88). Measurement of total nitrogen in plants and agars showed that nitrogen from impurities (probably protein) in the agar was transferred from agar to plant by bacterial action; less nitrogen was transferred from purer types of agar. Two other test plants, *Cucumis sativus* and *Dactylis glomerata*, responded like the *Trifolium* sp. Six soil fungi

(species of *Cladosporium, Pullularia, Pythium, Verticillium, Gliocladium*) and a culture of *Rhizophagus* as well as another *Pseudomonas* sp. also released bound nitrogen from agar. No nitrogen was transferred when the inoculum was either an *Endogone* species producing mycorrhizal infection of the clover or *Rhizobium phaseoli* which does not form nodules with clover.

To study the mechanism of this nitrogen transfer, the clover seedlings were grown in water culture with egg albumen instead of agar as nitrogen source. Plants took up the following proportions of the added albumen N: clover alone, none; clover + *Pseudomonas*, 65%; clover + *Pseudomonas* + glucose, 15%. When the *Pseudomonas* was grown alone on this medium, 75% of the added albumen N was recovered as free ammonia in the culture fluid, but only 25% when glucose also was added. The protein without glucose may not have supplied enough carbon and energy for the assimilation of more than a small proportion of its nitrogen by the micro-organisms. (Cooper, Jackson and Mosse.)

The establishment of mycorrhizal infection under aseptic conditions

Earlier work showed that *Endogone* alone did not establish a mycorrhizal infection under aseptic conditions, but did so in the presence of a species of *Pseudomonas* from soil. Additions of either Seitz-filtered suspensions of *Pseudomonas* sp. in water, of " Pectinol " or EDTA also enable the fungus to penetrate the root. None of the sterile filtrates was as effective as the live inoculum; each induced fewer infections, acted more slowly and was sometimes without effect. Autoclaving further lowered but did not destroy the effectiveness of the " Pectinol " and bacterial filtrates. Omitting calcium from the medium or replacing it by potassium greatly decreased infection, but calcium could be replaced by sodium without affecting infection. The factors controlling fungal entry into the root remain to be explained; the results suggest that changes in the pectin compounds of the cell wall are involved in the infection process. (Mosse.)

Effects of mycorrhizal infection on the growth of Trifolium parviflorum

Mycorrhizal seedlings grown aseptically in a nitrogen-deficient mineral salt medium were the same size (total dry wt.) as control plants. Individual mycorrhizal roots on infected seedlings were often strikingly longer and more branched than uninfected roots on the same seedlings. No net gain in nitrogen was demonstrated either in the infected seedlings or in the agar.

Mycorrhizal seedlings were transplanted from aseptic culture into autoclaved soil mixtures and grown in the greenhouse. Two months after transplanting in compost containing peat, mycorrhizal seedlings weighed more than non-mycorrhizal controls, but without peat growth was unaffected. (Mosse.)

BOTANY DEPARTMENT

D. J. Watson

Mr. Jamaludin bin Lamin left in August to return to the Department of Agriculture, Malaya. Other visitors from abroad were Dr. J. P. Riches, of the Botany Department, University of Adelaide, who worked here on water relations of seedlings until the end of January, and Miss M. E. Fitzpatrick, of the Scott Agricultural Laboratories, Nairobi, who was with us in May and June. Many more paid short visits to talk with us about the growth of tea, tobacco, rubber, coffee, cacao, sorghum, maize and vines as well as the crops that are familiar to us.

K. J. Witts was awarded a Ph.D. degree of the University of London. Joan M. Thurston attended the meetings of the European Weed Research Council and the 1st French Weed Control Conference in Paris in December.

In November we acquired some additional laboratory space in the building formerly occupied by the A.R.C. Unit of Plant Morphogenesis and Nutrition, and now to be called the Plant Physiology Laboratory. In part exchange, we surrendered a room to the Library.

Our work continued to deal with two main themes, weeds and the physiology of plant growth and yield. The weed studies were on the biology of weed species, effects of weeds on crop yield, and the nature of interference between weeds and crops. The physiological work included growth analysis studies on field crops, and laboratory and glasshouse investigations of related topics, including particularly the physiology of growth of leaves, and effects of some growth-regulating substances.

Weed Studies

Wild oats

More collections of wild oats seeds from several countries in Europe, and also seeds of *Avena sterilis* from Israel and of *A. ludoviciana* and *A. fatua* from Iraq were grown in pots in comparison with the sorts that are common in Britain. This experiment and a similar one in 1960 (*Rep. Rothamst. exp. Sta.* for 1960, p. 103) showed that the time of flowering varied more widely with the country of origin than between species. Thus, *A. fatua* and *A. ludoviciana* from Russia both reached 50% ear emergence in 124 days from sowing, *A. fatua* from Iraq in 97 days, and four selections of *A. ludoviciana* from Iraq in 94–101 days. Similarly, the interval between sowing and 50% ear emergence of *A. sterilis* from Israel was 93 days, from Crete 119 days and from France 134–140 days. Averaging all collections of all varieties in both years, the number of days from sowing to 50% ear emergence varied with the country of origin as follows: Israel 93, Iraq 97, Australia 114, Russia 124, Western Europe 129, Britain 135; it tended to be longer the higher the

latitude. Early-flowering plants had shorter culms than late-flowering plants of the same sort. The duration of ear emergence was longer in *A. ludoviciana* than in *A. fatua*, and still longer in *A. sterilis*, the species with the highest ear number.

Seeds harvested from these and earlier experiments have been kept in pans of watered soil in the glasshouse to test their dormancy and periodicity of germination. In selections of *A. sterilis* with four-seeded spikelets from the 1958 experiment, most of the first and second seeds germinated in the first year after sowing, the second seeds a little later than the first. Third and fourth seeds started later still; few germinated in the first year, and they continued germinating into the third year. In all years germination occurred only in late autumn and winter. This successive germination of seeds in the order in which they are borne in the spikelet is like that found for *A. ludoviciana*, of which first seeds in the spikelet mostly germinate in the first year after sowing and second seeds in the second year. A Greek selection of *A. ludoviciana* showed a similar germination sequence of seeds within the spikelet; it had more three-seeded spikelets than the British sorts, and the third seeds behaved like those of *A. sterilis*, germinating later than the first or second; a few were still dormant after three years. About half the seeds of a selection of *A. barbata* from Crete germinated in the first year, and fewer in the second and third years; some were still dormant after 3 years. The British sorts of wild oats grown as controls behaved as they did in previous glasshouse trials, except that three sorts had less persistent dormancy than before.

The experiment arranged by the International Research Group for Weed Control on the effects of storage conditions on dormancy and viability of seeds of *A. fatua* (*Rep. Rothamst. exp. Sta.* for 1960, p. 103) give similar results in all six European countries that co-operated. The percentage germination of ripe seeds at the time of collection was less than 10%, and except in Denmark increased rapidly in all storage conditions to 50% by December or January, when the seeds were 5–6 months old. Viability changed little during 1 year of storage, except that many seeds died when kept outdoors in winter in Denmark and Germany. In Denmark there was a sharp decrease in viability after only 3 months outdoors. The Danish results also differed from those of other countries in that the maximum germination in 7 months from harvest was only 20% of viable seeds, and dormancy persisted until February or March.

Dormancy of seeds of *A. ludoviciana* induced by high temperature can be broken by soaking them in a solution of gibberellic acid (*Rep. Rothamst. exp. Sta.* for 1959, p. 82). Further work on this in 1960 was frustrated because the moist plastic sponge on which the seeds were set to germinate was found to be contaminated with a laboratory detergent (Byprox) used in washing it. Soaking in a 1% solution of the detergent for 24 hours at temperatures between 7° and 21° C. inhibited germination of *A. ludoviciana* seeds held subsequently at the same temperature. It also inhibited germination of *A. fatua* seeds at 21°, but a few germinated at the lower temperatures. Ungerminated seeds became swollen and the endosperm was liquefied, but the embryos remained viable, and nearly all germinated within a week when the seed coat was cut. Soaking wild oats seeds

in tap water at 21° C. caused a decrease in subsequent germination at the same temperature that was greater the longer the time of soaking, but there was no effect at lower temperatures. Addition of 25 p.p.m. gibberellic acid to the water in which the seeds were soaked overcame the dormancy induced at 21° C. in seeds of *A. ludoviciana*, especially when the period of soaking was long, but had no effect on germination of *A. fatua*. (Thurston.)

Broadbalk weeds

Unusually late sowing of Broadbalk field, on 18 January 1961, decreased winter-germinating *Ranunculus arvensis* (corn buttercup), but contrary to expectation there was a heavy infestation of *Alopecurus myosuroides* (black grass). Previously, late sowing has suppressed *Alopecurus*, because its germination is usually completed by mid-November, and late seedbed cultivations destroy the seedlings (*Rep. Rothamst. exp. Sta.* for 1958, p. 85). The high density of *Alopecurus* plants may be partly attributable to heavy seeding in the previous season. Decreased competition by the delayed growth of wheat in spring allowed the *Alopecurus* plants to grow large, with numerous inflorescences, but this is unlikely to be the whole explanation of the heavy infestation. The wet, nearly water-logged condition of the soil in autumn that prevented sowing of the wheat may also have induced dormancy in *Alopecurus*, and this is being tested in a glasshouse experiment.

Section 3, after fallow in 1960, was as heavily infested with *Alopecurus* in 1961 as the parts of the field after wheat. It is unlikely that the plants on section 3 came from dormant seeds, as normally only about 3% are dormant, and very little *Alopecurus* seeded in 1959. The seed may have spread from neighbouring sections in 1960, but there was no evidence that the infestation on section 3 was denser at the edges next to cropped sections than in the middle. (Thurston.)

Effect of combine-harvesting on distribution of weed seeds

Completed analysis of the samples taken from Broadbalk field in 1958 (*Rep. Rothamst. exp. Sta.* for 1958, p. 84) showed that of the 24 million weed seeds per acre removed from the field, 7 million appeared in the first grade grain, 12 million in the seconds, 4 million in the rubbish separated from the grain and $1\frac{1}{4}$ million in the baled straw. Only about 1 million (4%) were left on the ground. The distribution of weed species depended on the seed size. Large seeds, e.g., *Vicia sativa* (common vetch), or inflorescences containing seeds, e.g., *Medicago lupulina* (black medic), appeared in the first-grade grain. Smaller seeds, such as *Polygonum aviculare* (knot grass), occurred mainly in the seconds, and very small seeds, such as *Papaver spp.* (poppies), were about equally divided between the rubbish and the fraction shed on the ground. The baler actually picked up some *Stellaria media* (chickweed) and *Medicago* that had not been cut by the combine. (Thurston.)

Interference between weeds and crop

Weed density and crop yield. In 1960 small plots in non-experimental fields of winter wheat were covered with polythene sheets to

protect the weeds when the crops were sprayed with herbicide in spring, the numbers of weed seedlings of different species present on the plots at the time of spraying were counted or estimated, and the yields of wheat at maturity were determined (*Rep. Rothamst. exp. Sta.* for 1960, p. 105). A multiple-regression analysis of the results showed that only where the autumn-germinating weeds *Galium aparine* (cleavers) or *Stellaria media* (chickweed) occurred were there significant regressions of wheat yield on weed density. Grain yield was decreased by 4% and straw yield by 2% by an increase in *Galium* seedlings of 10 per sq. yd. within the range 0–100 per sq. yd. The corresponding effects of increasing density of *Stellaria* were less than 1% (not significant) by 10 additional seedlings per sq. yd. for grain yield and just over 1% for straw yield over a similar density range to that of *Galium*. *Polygonum persicaria* (redshank) also may have had a small effect on straw yield.

Experiments of this sort are difficult to interpret, because weed density and crop yields may both be affected by fertility differences, either directly or indirectly through variation in numbers of weed seeds in the soil caused by difference in weed growth in previous seasons. An alternative method of measuring the dependence of crop yield on weed density is to sow both weed seeds and crop seeds on land previously treated to minimise the natural weed infestation. This was done in 1960 and 1961 on a garden plot that had been fallowed in 1959. Seeds of *Chenopodium album* (fat hen), *Capsella bursa-pastoris* (shepherd's purse) and *Stellaria media* were broadcast on small plots in March 1960 at three rates (including none) in a factorial arrangement. Soon afterwards the plots were combine-drilled with Jufy I spring wheat and fertiliser. They were irrigated in dry periods to encourage germination and growth of the weeds. The treatments were repeated on the same plots in 1961. The numbers of weed plants established on the plots were at best only about half the expectation from laboratory germination tests; in 1960 there were very few *Capsella* plants, and in 1961 few *Chenopodium* plants. In 1960 only *Chenopodium* significantly affected the yield of wheat; the higher rate of sowing, which gave 38 plants per sq. ft., decreased both grain and straw yield by 6%. In 1961 the experiment was spoilt by an attack of " take-all " that made the wheat yields very variable, and the only significant effect, though barely so, was a decrease in straw yield of 12% by *Capsella*. In spite of the large numbers (160 per sq. ft. at the higher rate) of *Stellaria* plants and their vigorous growth, they apparently decreased yield by only about 9%.

Another estimate of the loss of crop caused by weeds was obtained from the experiment on winter and spring varieties of wheat (p. 86). The spring-sown plots had a uniform population of *Polygonum convolvulus* (black bindweed), with an average density of 30 seedlings per sq. ft., which was controlled by spraying with a 2,3,6-TBA/MCPA mixture in early May. At the time of spraying the weeds on parts of each plot were protected with polythene sheet. The yield of straw on these areas was about 10% less than that of the sprayed crop, but the weeds had no effect on grain yield. (Welbank and Witts.)

Competitive effects of Agropyron repens *and* Agrostis gigantea

The rhizomatous grasses, *Agropyron repens* (couch grass) and *Agrostis gigantea* (common bent), occupy analogous places in the weed flora of the heavy soil at Rothamsted and the light soil at Woburn, respectively. In the Woburn soil *Agrostis* competes more successfully with wheat for nitrogen supplied late in the growing season than for early supplies (*Rep. Rothamst. exp. Sta.* for 1958, p. 88). Nitrogenous fertiliser applied in May increased the yield of wheat growing in competition with *Agrostis* less than an application in early April, because the wheat secured a smaller fraction and *Agrostis* a larger fraction of the late nitrogen supply than of the early. A pot experiment was done in 1961 to find whether competition between wheat and *Agropyron* depends on nitrogen supply in a similar way, to compare the competitive effects of the two grass weeds in Rothamsted and Woburn soils and to test whether the results depend on the size of pot, as it might do if contact with the walls of the pot affects the growth of rhizomes. Pots were harvested at intervals to measure growth in dry weight and provide material for determining nitrogen uptake.

In Woburn soil the effects of competition with *Agrostis* were as before; *Agropyron* also gave similar results in large pots, but in smaller pots caused a greater decrease of wheat yield with early nitrogen applications than with late. In Rothamsted soil the responses of wheat and both grasses to additional nitrogen were less than in Woburn soil. The competitive effects also were different. *Agrostis* decreased wheat yield more with early than with late nitrogen, but the effects of *Agropyron* were the same for both times of nitrogen application. In Woburn soil both grasses had much larger root systems than wheat, but they were smaller in Rothamsted soil, whereas those of wheat were of similar weight in both soils. These results cannot be fully interpreted until the nitrogen estimations and the statistical analyses of the results are completed. (Witts and Welbank.)

Previous work showed that *Agropyron* depresses the growth of crop plants by root competition for mineral nutrients, particularly nitrogen. The intensity of root competition is likely to depend on light intensity, because in low light intensities the requirement of mineral nutrients for growth may be diminished. In a pot experiment to test this, young sugar-beet plants were transplanted into soil with or without established *Agropyron* plants, three rates of nitrogen supply were compared, and pots were grown in the open or under shades that passed about one-third or two-thirds of the incident light.

Without competition, the growth of sugar-beet plants increased with increase in light intensity, but the difference between the intermediate and high intensities was small. Nitrogen also increased growth at the high and intermediate light intensities, but had little effect in the low intensity. Competition with *Agropyron* had no effect on growth of sugar beet in the low light intensity, but without added nitrogen it greatly decreased growth in the higher light intensities. The effects of competition were almost eliminated by increased nitrogen supply, indicating that the competition was for

nitrogen. These results conform with the hypothesis that low light intensity so diminished the requirement of the sugar-beet plants for nitrogen that their growth was unaffected when part of the supply from the soil was removed by *Agropyron*, but a possible alternative explanation is that low light intensity restricted growth of the roots of both sugar beet and *Agropyron* so that they intermingled less. (Welbank.)

Production of toxic substances in soil by decay of plant material

Decay of rhizomes and roots of *Agropyron repens* in poorly aerated soil produces substances toxic to seedlings (*Rep. Rothamst. exp. Sta.* for 1960, p. 106). Experiments were done to test whether other plant species have a similar effect. Rhizomes of *Agropyron* or of *Agrostis* sp. (probably *tenuis*), or stem bases of *Lolium multiflorum* (Italian ryegrass) or *Medicago lupulina* (cultivated trefoil), both of which are used as green-manure crops, were cut up and mixed with an infertile Rothamsted soil, Woburn soil or with a fibrous loam from Kettering. Enough water was added to puddle the soil, and the samples were incubated in stoppered jars for 3–4 weeks at 20° C. The samples were then extracted with water, and the extracts sterilised and assayed for toxicity by measuring their effects on elongation of radicles and hypocotyls of rape seedings.

Compared with extracts of soil alone, all the extracts of plant materials inhibited radicle elongation, with no significant difference between species. The toxic effects were slightly greater in Kettering loam than in the other soils. Only *Agropyron* extracts consistently inhibited hypocotyl elongation. The other species, particularly *Medicago*, gave extracts that increased hypocotyl growth, and this stimulation was greater for Woburn soil than for the others. Restriction of radicle growth may have enabled the hypocotyls to secure an increased supply of nutrients from the seed. When incubated alone the Kettering soil gave more inhibitory extracts than the others, and probably the organic matter in this soil was itself enough to produce appreciable amounts of inhibitor by anaerobic decomposition. Evidently the production of toxic substances by decay is far from being a specific property of *Agropyron* rhizomes and roots, but the *Agropyron* extracts had effects on hypocotyl growth not shared by the other species tested. (Welbank.)

Physiology of Growth and Yield

Old and new varieties of winter and spring wheat

Spring wheat has been so much improved recently that the grain yield of some new varieties approaches that of winter wheat. To find how this happens despite the much longer growth period of autumn than of spring sowings, and how breeding has affected growth so as to increase yield, a field experiment was done in 1960 to compare old and new varieties of winter wheat (Squarehead's Master and Cappelle-Desprez) and of spring wheat (Atle and Jufy I), without or with nitrogenous fertiliser (0·6 cwt. N/acre) applied at the time of spring sowing. Samples were taken at intervals throughout the growing season to measure dry weight, leaf area and other growth

attributes, and nitrogen content. Mean yields of grain in cwt. dry matter per acre were: Cappelle 35, Jufy I 29, Squarehead's Master 21, Atle 20. Nitrogen increased the yields of Cappelle and Jufy I by 6 cwt./acre, and of Atle by 2 cwt./acre, but it decreased the yield of Squarehead's Master by 5 cwt./acre by causing severe lodging. There was also a little lodging in Squarehead's Master without nitrogen.

Until ear emergence the winter varieties had more shoots and greater leaf area and total dry weight than the spring varieties. Cappelle had less leaf area than Squarehead's Master, but Jufy I had more than Atle. Nitrogenous fertiliser increased leaf area. These differences in leaf area were accompanied by differences in the opposite sense in net assimilation rate (E). Thus, during May and June E of the spring varieties greatly exceeded that of the winter varieties, and nitrogen decreased E. However, when the mean values of E in this period were corrected to constant mean leaf area index (L) by a regression of E on L, the differences between varieties in E and the decrease in E by nitrogenous fertiliser all disappeared, except that mean E for the winter varieties remained slightly, though not significantly, below that of the spring varieties, and this if real may represent an age effect. So it is reasonable to assume that the differences in E between varieties and the effect of nitrogen on E were caused by differences in mutual shading of leaves associated with the differences in L, and not by differences in leaf physiology affecting photosynthetic rate.

After ear emergence the spring varieties continued to have smaller total dry weights than the winter varieties, but their ear dry weights were only slightly less, so that their ear : shoot ratios were greater. Total and ear dry weights and ear : shoot ratio were greater for Cappelle than Squarehead's Master and for Jufy I than Atle. There were only small differences between varieties in number of shoots after ear emergence, so high grain yield and dry weight of ears were associated with large ears, especially in Jufy I, which had the fewest shoots. The leaf area present after ear emergence, which produces most of the dry matter in the grain, measured as leaf area duration (D) after the date of 50% ear emergence, was little greater for winter than for spring varieties, and this is the reason for the similarity in their grain yields. The efficiency of the leaves, expressed as the ratio of final grain yield to D, was the same for winter and spring varieties. However, it was greater for Cappelle than Squarehead's Master and for Jufy I than Atle. It is unlikely that the leaves of the new varieties had higher rates of photosynthesis than the old ones at this time, because before ear emergence there was no difference in E except that attributable to differences in leaf area. The explanation of the apparently greater efficiency in grain production of the leaves of Cappelle and Jufy I is presumably that photosynthesis by the ears of these varieties contributed more to grain yield than ears of Squarehead's Master or Atle. Thus, in both winter and spring wheats, as in barley,* the higher grain yield of new varieties was associated with a larger ear : shoot dry weight ratio that was partly attributable to more photosynthesis by the ears. (Watson, Thorne and French.)

* Watson, D. J., Thorne, G. N. & French, S. A. W. (1958). *Ann. Bot. Lond.* N.S., **22**, 321–352.

Photosynthesis by ears of Proctor and Plumage Archer barleys

In a previous field experiment (*Rep. Rothamst. exp. Sta.* for 1960, p. 98) shading ears decreased the grain size of Proctor and Plumage Archer barleys equally, but decreased the numbers of grains, and hence dry weight per ear, of Proctor more than of Plumage Archer. However, in the field in 1961, as in all previous pot experiments, shading ears decreased the numbers of grains of both varieties equally. Grain size and dry weight of grain per ear of Proctor were decreased slightly more than those of Plumage Archer. Proctor had more ears per acre, and the contribution by ear photosynthesis to yield of grain per acre, as estimated by shading, was 70% greater for Proctor than for Plumage Archer.

The reversal of the varietal difference in ear : shoot dry weight ratio that occurs between ear emergence and maturity was studied in pots (*Rep. Rothamst. exp. Sta.* for 1960, p. 98), where Proctor and Plumage Archer do not differ in yield, but hitherto not in conditions where Proctor shows its usual superiority of yield. In a field experiment done in 1961 Proctor produced 12% more grain than Plumage Archer, and the ear : shoot ratio was again greater for Plumage Archer at emergence but for Proctor at maturity. This reversal occurred whether or not ears were shaded, and was wholly caused by the greater relative growth rate of Proctor ears. Proctor shoots decreased in weight less than Plumage Archer shoots, the opposite of the varietal difference observed in pots. Leaf-area duration after ear emergence and the efficiency of leaves in grain production of shoots with shaded ears were both similar for Proctor and Plumage Archer.

In this field experiment yields of Proctor and Plumage Archer grown with 7-inch or 14-inch spacings of the rows were compared, to test whether the lack of varietal difference in yield in pots was a consequence of the greater light intensity at the base of the plant in pots than in the field. However, Proctor yielded more than Plumage Archer at the wide as well as the close spacing.

The measurements of CO_2 uptake by photosynthesis and loss by respiration of shoots of Proctor and Plumage Archer made with an infra-red gas analyser in 1960 on plants grown in pots (*Rep. Rothamst. exp. Sta.* for 1960, p. 98) were repeated in 1961 on randomly selected shoots of the two varieties growing in adjacent field plots, starting 7 days after the ears began to emerge. Rates per shoot of apparent photosynthesis and respiration of the ears, and of the flag leaf, sheath and peduncle were slightly greater for Plumage Archer than for Proctor. This was because Plumage Archer shoots had larger ears and greater leaf area; rates of apparent photosynthesis of the leaves per dm.^{2} and of respiration per g. dry weight were similar for the two varieties. Rates per shoot of apparent photosynthesis of ears and leaves remained constant until about 3 weeks after ear emergence and fell to zero during the next 2 weeks. (Thorne.)

Effects of drought on crop growth

When a sugar-beet crop suffering from drought is irrigated, even with quantities of water much less than the soil-water deficit, it may for a time grow faster than a continuously irrigated crop, and so

compensate for slow growth during the drought period (*Rep. Rothamst. exp. Sta.* for 1958, p. 79, and for 1959, p. 77). The extent to which a crop can recover from a check to growth caused by drought depends on the severity of the drought (the soil-water deficit), the size of the plants and the weather during the recovery period. Previous experiments have been done in summer, but another was started in August 1960 to see whether recovery from drought can occur in the unfavourable growth conditions of autumn and winter. Seedlings raised in soil blocks were transplanted to the Dutch-light glasshouse and kept free from water stress by irrigation until 8 September. Some plots then continued to be irrigated, and on others water was withheld until 3 November. On some of the unwatered plots water was then given to make up the soil deficit of 1·7 inches; other plots received only $\frac{1}{4}$ inch of water, and still others continued without irrigation. Samples of plants were taken to estimate dry weight, leaf area and water content in October, early and late November 1960 and in early January 1961.

Growth was slow and the leaf area index (L) never exceeded 1·3. By early November, L was decreased by a quarter on plots unwatered for 2 months, but the small decrease in total dry weight was not significant. When water was then given at the higher rate there was nearly complete recovery in L, but the low rate of watering had small and transient effects much less than in previous experiments. Continued drought for 4 months decreased total dry weight by one-third and halved L mainly by decreasing leaf size; leaf number was only slightly affected. Net assimilation rate was not significantly affected.

No further work was possible until June, as the Dutch-light glasshouse was moved to another site, doubled in size and equipped with automatically-metered spray lines. An experiment was started in June and continued until August, to test whether recovery from drought depends on light intensity, by covering parts of the plots with white cotton shades in the period after rewatering when the soil water deficit had reached 3 inches. The results of this experiment are not yet fully analysed. (Orchard.)

Profiles of photosynthetic rate in field crops

A method of studying the profile of photosynthetic rate, i.e., its variation with height in a field crop, based on measurements of the net assimilation rate (E) of sugar-beet seedlings (phytometers) growing in nutrient solution and supported at varying heights within the crop for periods of about one week, was described in *Rep. Rothamst. exp. Sta.* for 1960, p. 97. Results of experiments in 1960 showed that phytometer E was less inside crops than in the atmosphere above, and decreased towards the ground, but remained positive at ground level in all crops between mid-June and September. Near to the top of the crop, the rate of decrease of E with depth was faster in kale than in sugar beet or potatoes, for which it was similar. Results for barley were variable and need to be repeated. The vertical distribution of leaf area index (L) of the crop, determined by layered sampling, showed that E decreased linearly with increase in the logarithm of L of the part of the crop above the phytometer. The decrease was faster for kale than for

the other crops, and slowest for barley. This difference presumably means that less light penetrates through unit L of kale than of the other species. The results agree with the hypothesis* that E decreases less rapidly with increase of L so that maximum crop growth rate occurs at a much higher L for sugar beet than for kale crops, because a difference in spatial arrangement of the leaves causes more uniform illumination throughout the profile in sugar beet than in kale. (Leach.)

Dependence of photosynthesis on growth

More evidence is accumulating to suggest that the rate of photosynthesis of leaves depends on how rapidly photosynthetic products are used in growth of other parts of the plant. Rooted detached leaves are particularly suitable for studying this problem, because they have a relatively small sink for photosynthetic products that can be varied in size experimentally.

Detached primary leaves of dwarf French bean kept with their petioles dipping in nutrient solution produce adventitious roots, and survive for several weeks with little increase in area before becoming senescent. They have a low net assimilation rate (E) of about 10 g./m.^{2}/week throughout their life. Experiments done at various times from March to December showed that E varied little with season, indicating that it is controlled by internal factors. About three-quarters of the dry matter accumulated after a leaf was detached remained in the lamina, and most of the rest passed to the roots. The dry weight of lamina increased from about 2 mg./cm.^{2} at the time of detachment to 6 mg./cm.^{2} after 6 weeks when the leaf was becoming senescent and E began to decrease. When petioles of detached leaves were treated with indolylacetic acid before they were placed in nutrient solution they formed more roots and had a higher E than untreated leaves (*Rep. Rothamst. exp. Sta.* for 1960, p. 102). In experiments in 1961 root growth was increased by raising the temperature of the nutrient solution from about 12° to 24°, near the optimum for root growth. At 24° a larger fraction of the photosynthate passed into the roots, the rate of accumulation of dry matter in the lamina decreased, and E was increased. Similarly, when the size of the vessel containing nutrient solution was increased from 600 ml. to 3 l. the root system grew larger and E was doubled. These results suggest that photosynthetic products, which accumulated in the lamina because their use in growth was restricted, depressed the rate of photosynthesis, and may eventually have caused senescence of the leaf. (Humphries.)

Sugar beet and spinach beet are varieties of *Beta vulgaris* that differ in the size of their storage roots and the amount of sugar they accumulate, but otherwise are very similar. To find whether this difference is associated with different rates of photosynthesis by the leaves, plants of the two varieties were grown in pots and their dry weights, leaf areas and net assimilation rates were determined by sampling on four occasions in June and July. Total dry weight of sugar beet was always greater than that of spinach beet, and the difference increased with time; it was entirely attributable to the

* Watson, D. J. (1958). *Ann. Bot. Lond.* N.S., **22**, 37–54.

greater dry weight of the root of sugar beet. The leaf areas of the two varieties were similar, and E of sugar beet was therefore greater than of spinach beet in each interval; on the average it was 56% more. There was no obvious difference between the varieties in leaf arrangement that might affect mutual shading, and respiratory loss of dry matter by spinach beet was probably less than by sugar beet because of its smaller root, so the difference in E can be ascribed to lower photosynthetic efficiency of the leaves of spinach beet than of sugar beet. It may be a consequence of the greater use of photosynthetic products by growth and sugar storage of the root of sugar beet, that is, of the more efficient sink for carbohydrate. However, it is also possible, though unlikely, that the larger storage root of sugar beet is a consequence and not the cause of the higher photosynthetic rate of sugar beet. It may be possible to decide between these alternatives by studying the growth of reciprocal grafts between roots and tops of sugar beet and spinach beet. (Thorne.)

Growth on different soils

The study of the physiological basis of variation in yield of sugar beet between different soils (*Rep. Rothamst. exp. Sta.* for 1960, p. 96) was continued and extended in 1961. Experiments were done at six centres with widely contrasting soils, including three of the four used in 1960. As before, the crop was grown with and without nitrogenous fertiliser at each centre, and at Rothamsted and Broom's Barn two dates of sowing were compared. Samples were taken at fortnightly intervals from May to November, to estimate leaf area and the dry weight and water content of the plant parts, and for subsequent analyses of mineral nutrient and sugar contents.

At the centre with the highest yield in 1960, on a silt soil near Holbeach, the yield of dry matter was still higher in 1961, but at the other two centres for which a comparison between years is possible, at Rothamsted and on a calcareous soil near Stamford, it was much lower in 1961, especially without nitrogenous fertiliser. These differences in yield between sites and years were associated with similar differences in leaf-area index, but it is not yet known whether there were also differences in net assimilation rate. It is intended to repeat the work in 1962 at the same centres as in 1961, and then to make a combined analysis of the three years' results. (Goodman.)

Effects of gibberellic acid on the growth of potato and sugar beet

Our interest in gibberellic acid (GA) is mainly in its effects on leaf growth. Potato plants sprayed with solutions of GA produce larger leaves, and for a time correspondingly more dry matter, but the leaves soon become paler, and later their photosynthetic efficiency decreases, so that the final weight may be unaffected, though in a pot experiment in 1960 the yield of total dry weight and of tubers was increased. The onset of the change in colour was not prevented by increased supply of nitrogen (*Rep. Rothamst. exp. Sta.* for 1959, p. 72, and 1960, p. 99).

The 1960 experiment not only tested nitrogen but also whether the effects of GA depend on the supply of phosphorus or potassium. The plants were sprayed twice with GA solution in May. As before,

GA increased the area of leaves on the main axis, but decreased their length of life. Leaf production on the lateral branch of node 9 was decreased by GA, but was increased at higher nodes. GA had no effect on the size of lateral leaves.

Nitrogen decreased the number of leaves on the main axis, increased their size and lengthened the life of the lower leaves, but shortened it at higher nodes. These effects of nitrogen on longevity were enhanced by GA. Nitrogen increased leaf production and longevity on lateral branches. Phosphorus and potassium had little effect on the growth of leaves on the main axis, but increased the size of lateral leaves in the later stages of growth, and phosphorus lengthened their life. There was no interaction of GA with phosphorus or potassium.

Cells were counted in disks of known area cut from leaves 7, 11 and 15. The disks were stored in EDTA solution, and immediately before counting were incubated with pectinase to separate the cells.* The results were obscured by a gradient, probably of temperature, along the glasshouse; GA decreased the number of cells per disk, particularly in the warmer part of the glasshouse. Mean cell size was similar in leaves 7 and 11, but smaller in leaf 15. GA increased cell size in leaves 7 and 11 but not in leaf 15; it also increased cell number per leaf by about 25%, even in leaf 15, which had not expanded when the plants were sprayed. These results show that GA promotes cell division as well as cell extension in intact leaves. Nitrogen increased cell number, and in leaf 15 phosphorus did also. Potassium decreased cell number per leaf but increased cell size.

In 1961 the effect of GA on leaf growth of sugar beet was studied in a pot experiment. Young sugar beet were sprayed with 50 mg. GA/l. or with water on 2, 4 or 6 occasions at weekly intervals. GA increased leaf size but decreased leaf number, and on balance did not change the total leaf area per plant. Consequently, in contrast to the results for potato, there was no effect on the rate of dry-matter production, either immediately after spraying or later. GA increased the length of the main axis, but much less than in normal bolting, and it did not cause flowers to form. It decreased the length of the petioles. (Humphries and French.)

Gibberellic acid is not known to occur in higher plants, but other gibberellins do. The one in potato leaves that promotes the growth of disks cut from etiolated dwarf French bean leaves (*Rep. Rothamst. exp. Sta.* for 1960, p. 101) and presumably controls the expansion of potato leaves was identified as gibberellin A_5 (5·8). The fate of gibberellic acid sprayed on potato plants was further studied. Spraying with a solution of 50 mg. GA/l. just before the 15th leaf expanded, increased the growth of the 15th leaf. Gibberellins in the 15th leaf of sprayed and unsprayed plants were estimated by bioassays of chromatograms of ethyl acetate extracts. Total gibberellins (including GA) were assayed with disks of etiolated French bean leaves, and GA with lettuce hypocotyls, the growth of which is not affected by gibberellin A_5 or the gibberellin from potato leaves (5·8). The 15th leaf of unsprayed plants did not contain GA. The 15th leaf of sprayed plants contained much 1 week after spraying, but the amount decreased to a low value after 3 weeks. Meanwhile, the

* Humphries, E. C. and Wheeler, A. W. (1960). *J. exp. Bot.*, **11**, 81–85.

total gibberellin content increased to four times that in untreated leaves, indicating conversion of GA to a gibberellin, possibly A_5, inactive on lettuce hypocotyls. However, conversion to gibberellin A_5 of all the GA present one week after spraying would not account for the total gibberellin content after 3 weeks, so gibberellins formed from GA in lower leaves were probably transported to the 15th leaf. The ethyl acetate extracts were also used for chlorophyll estimations. The total chlorophyll content of the 15th leaf was increased by GA, but as the sprayed leaves were larger, they had less chlorophyll per unit area than unsprayed leaves, and this accounts for their being a paler green. (Humphries and Wheeler.)

Effects of a growth regulator, CCC

Some quaternary ammonium compounds have growth-regulating properties opposite to those of GA; in particular, they diminish stem extension and produce stunted plants. One compound 2, chloroethyltrimethyl ammonium chloride, also called chlorocholine chloride (CCC), was tested in the 1961 sugar-beet and potato experiments, alone and in combination with GA. CCC is closely related chemically to betaine, which occurs in sugar beet. It was applied to the soil at the rate of 150 or 200 ml. of a $10^{-2}M$ solution per pot.

When applied to sugar beet simultaneously sprayed with GA, CCC had no effect on leaf growth, but decreased the stem elongation caused by GA. CCC on its own increased the rate of leaf production by 20%, but decreased leaf size and total leaf area. It also decreased the small amount of stem extension that occurs in untreated sugar beet, so that the " crowns " were shorter and flatter. However, it increased the length of petioles, again an effect opposite to that of GA. (Humphries and French.)

CCC alone slightly decreased the area and gibberellin content of the 15th leaf of potato plants. In plants also sprayed with GA, CCC increased the area and gibberellin content slightly, but the GA content was unaffected. Thus, CCC apparently increased transport to the 15th leaf of gibberellins, presumably produced from GA in older leaves. It had no effect on chlorophyll content. (Humphries and Wheeler.)

The effect of CCC on leaf expansion was tested by the bean-leaf-disk method of assay for leaf-growth substances. CCC at $10^{-3}M$ did not affect the growth in darkness of disks cut from etiolated leaves, but decreased their greater growth in light. Growth promotion by GA added to the test solution was decreased or wholly suppressed by CCC. Thus, inhibition of growth of bean leaf disks by CCC depended on the presence in the tissues either of endogenous gibberellin, i.e., during growth in light, or of GA supplied from the external solution. Similar results were obtained with the analogous compound bromocholine bromide. (Wheeler.)

The effects of CCC were also tested on tobacco, mustard and radish. The tobacco plants were grown in nutrient solution without CCC, or with CCC present in the solution continuously or in alternate fortnights, starting when the plants had four leaves. In the continuously treated plants CCC decreased the length of leaves 7–20, but increased the length of leaves produced later. The treated plants maintained a rosette habit and did not elongate until about

20 leaves were formed, when the stem extended rapidly in spite of continued treatment with CCC. The discontinuous supply of CCC had less effect on leaf growth, and ceased to inhibit stem elongation after 15 leaves were formed.

The older leaves of plants treated with CCC, which were shorter than those of untreated plants, were also wider and probably thicker, so the total leaf dry weight was unaffected. Total dry weight per plant was decreased by CCC, but the difference was wholly in the stems. Treatment with CCC increased the chlorophyll content of the leaves.

The mustard and radish plants were grown in soil with 0, 75, 150 or 225 ml. per pot of a $10^{-2}M$ solution of CCC. The 75-ml. dose increased the weight of leaves on the main stem, 150 ml. had no effect and 225 ml. decreased it. CCC had no effect on the number of leaves on the main stem, but increased the number and total area of leaves on lateral branches. The smallest dose of CCC more than halved the dry weight of the main stem, and larger doses had a greater effect, but the changes in weight of stem of lateral branches were much smaller.

The most interesting result is that although treatment with CCC had little or no effect on total leaf weight or area of tobacco, and in mustard increased them, it greatly decreased stem weight of both species, so that the leaf-weight ratio and leaf-area ratio were increased. The decrease in dry matter produced, in spite of an increase in total leaf area, may be another example of restricted use of photosynthetic products slowing photosynthesis (p. 90), here because CCC inhibits stem extension, but there may be other explanations.

Radish was affected differently; the dry weights of all parts of the plant, except the hypocotyl, were decreased by CCC. This may be related to the difference in apical dominance between mustard and radish. (Humphries.)

BIOCHEMISTRY DEPARTMENT

N. W. Pirie

Mr. F. H. Shah (Pakistan Council of Scientific and Industrial Research) is working in the department during the tenure of a Colombo Plan Fellowship, and Dr. F-T Khouw was here for some months with a fellowship from the Food and Agriculture Organisation. Drs. P. M. Sankaran (Ministry of Defence, India) and Mumtaz Hussain (Ministry of Defence, Pakistan) visited briefly to examine the process of extracting leaf protein on a large scale.

Six members of the department attended the 5th International Congress of Biochemistry in Moscow. N. W. Pirie spent six weeks in India, at the request of the Indian Government and the Colombo Plan, reporting on the prospects of making leaf protein there. He also visited the U.S.A. to take part in a symposium on " Nutrition for an expanding world population ", organised by the Society for Economic Botany, and the " Woodring Conference on the Origins of Life ", organised by the U.S. Geological Survey.

Studies on Plant Proteins

The breakdown of chlorophyll

About 50 kg. sugar-beet leaves were processed to prepare chlorophyllase. Little further progress was made in purifying the enzyme, but preparations with high specific activity can now be made quickly and simply in reasonable yield. Cellulose phosphate is a much more efficient adsorbent than carboxymethyl-cellulose, and therefore gives a higher yield, but it is less specific, so gives preparations with lower specific activity. Electrophoresis shows the presence of three components in a 200-fold purified preparation.

Up to 40% of the chlorophyll of some leaves has been stated to be extracted by non-polar solvents, but preliminary investigation of its extractability by polar and non-polar solvents failed to confirm this. With most of the species tested less than 5%, and with none more than 10%, of the total chlorophyll was soluble in petroleum ether. Only young leaves have so far been examined, and solubility may change on ageing.

Chlorophylls *a* and *b*, pheophytins *a* and *b*, chlorophyllides *a* and *b* and pheophorbides *a* and *b* were all separated from each other by suitable variations of the proportions of petroleum ether, benzene and acetone in the running solvent and in the atmosphere of the tank in which the paper chromatograms are run.

Acetone extracts from French bean leaves give a red crystalline precipitate on standing in the cold. A tentative identification of this as carotene was confirmed by Dr. V. Booth of the Dunn Nutritional Laboratory. Carotene precipitation also occurred in acetone extracts from the leaves of several other species, but in amounts small compared with those from bean leaves grown in a glasshouse with extra illumination, from which as much as 0·1% of the dry

matter of the leaf will precipitate out of extracts containing about 80% acetone. (Holden.)

Plant amine oxidase, a copper-protein enzyme

A study of the inhibition of plant amine oxidase by chelating agents confirmed the suggestion, made last year, that the enzyme is a copper protein. The chelating agents used were 1 : 10-phenanthroline, 2 : 2-dipyridyl, 8-hydroxyquinoline, sodium diethyldithiocarbamate and potassium ethyl xanthate. At concentrations of 30–300 μM all these reagents completely inhibited the enzyme. The inhibitions could be prevented by adding metal ions to the reagents, to form the respective metal chelates, before the enzyme was added. Several metal ions, including Fe^{2+}, Co^{2+}, Ni^{2+}, Cu^{2+} and Zn^{2+} ions, partially or completely prevented the inhibition with all the reagents except potassium ethyl xanthate. Cu^{2+} ions generally appeared less effective than Co^{2+} or Ni^{2+} ions, because the enzyme was rapidly inactivated by Cu^{2+} ions during the course of the reactions it catalyses. When this inactivation by Cu^{2+} ions was prevented, by adding pyrophosphate to the reaction medium, Cu^{2+} ions completely prevented the inhibition by all the chelating agents and were the only metal ions that prevented the inhibition by potassium ethyl xanthate.

Except with sodium diethyldithiocarbamate, the same metal ions which prevented the inhibitions also reversed the inhibitions produced by preincubating the enzyme with the chelating agents. The inhibition of the enzyme by sodium diethyldithiocarbamate was partially or completely prevented by Fe^{2+}, Fe^{3+}, Co^{2+}, Ni^{2+}, Cu^{2+} and Zn^{2+} ions, but was reversed only by Cu^{2+} ions.

Estimations of the copper content of the enzyme preparations, after dialysis against the chelating agents, showed that copper was split off from the preparations by sodium diethyldithiocarbamate but not by the other chelating agents. Dialysis against water, to remove the chelating agents, reversed the inhibitions except that produced by sodium diethyldithiocarbamate, which was reversed only by Cu^{2+} ions.

The primary reaction producing the inhibition is probably the combination of the chelating agent with enzyme-bound copper to form an enzyme–inhibitor complex. These complexes are dissociable and generally break down, on dialysis or on adding metal ions with which the inhibitor forms a complex, to liberate the copper-protein enzyme. The enzyme–sodium diethyldithiocarbamate complex dissociates into copper-free protein and copper diethyldithiocarbamate complex; only Cu^{2+} ions can then reverse the inhibition.

The copper is firmly bound to the enzyme protein, and the amine oxidase may therefore be classified as a metalloenzyme. The enzyme is inactivated during the reactions it catalyses by hydrogen peroxide, which is one of the reaction products. Preliminary results suggest that Cu^{2+} ions catalyse this reaction–inactivation. Other copper-containing oxidases are subject to rapid reaction–inactivation and with one of them—ascorbic acid oxidase—the reaction–inactivation is also catalysed by Cu^{2+} ions. (Hill and Mann.)

Leaf protease

Protease activity per g. protein N in young leaves of spring wheat sown in a glasshouse in December or winter wheat sown in January increased rapidly when the shoot apex changed from the vegetative into the reproductive state; after this the activity soon fell to about half of the maximum. Activation and inhibition studies show that leaf protease belongs to the SH-group of enzymes. The starting activity of leaf extracts is so low that they are unpromising sources from which to purify protein-splitting enzymes, and the protein could not be purified more than five-fold. (Singh.)

Leaf mitochondria

Mitochondria are completely separated from chloroplasts by centrifuging leaf extracts in a " sucrose gradient "; separation from fragments of broken chloroplasts is less complete. This year a slight modification of the procedure increased the separations a little, still not enough to produce chlorophyll-free mitochondria, but enough to show whether particular enzymic activities are associated with mitochondria or chloroplasts. There is increasing interest in the enzymic capabilities both of purified chloroplasts and of mitochondria, so it seemed worth while to find what factors limited the usefulness of this method of separation.

Exposure to the high osmotic pressures of the sucrose solutions that form the gradient does not appreciably affect the activity of glycollic oxidase or the mitochondrial enzymes fumarase and cytochrome oxidase. Nor does it appear to affect the attachment or non-attachment of these enzymes to cellular particles. This is not so with malic dehydrogenase, another enzyme of the tricarboxylic acid cycle. The small amounts of activity present in crude mitochondrial or chloroplast preparations appear to be eluted during sedimentation in concentrated sucrose solutions. Such an elution of very loosely bound components is obviously a major limitation to the usefulness of the technique in its present form.

The cytochrome oxidase activity of tobacco-leaf extracts increases 2-4-fold after standing on ice for 24 hours. The effect of certain surface-active agents on this activation suggests that it may be caused by the slow disorganisation of the lipid-containing mitochondrial membranes, so allowing freer approach of the enzyme to its substrate, reduced cytochrome c. This increase resembles the activation of chlorophyllase that occurs when it is extracted from acetone powders of leaves, and also, but perhaps less closely, the activation of polyphenolase of broad-bean leaf extracts. These effects emphasise a difficulty in estimating enzymes in crude leaf extracts, especially those enzymes, like chlorophyllase and cytochrome oxidase, that are surrounded by, or are built into, membranes of cellular structures. (Pierpoint.)

Viruses

Highly infective preparations of cucumber mosaic virus were prepared from tobacco leaves disrupted in the presence of the copper chelating compound sodium diethyldithiocarbamate, but not otherwise. To study the copper-dependent inactivation of the virus,

attempts were made to construct model inactivating systems *in vitro*. One, produced simply by adding copper and chlorogenic acid to the dialysed leaf extract, probably depends on the polyphenol-oxidase present in the extract. It was extremely effective against virus preparations made in the spring and, as it is likely to operate during the disruption of infected leaves, most attention was given to it. However, progress was hindered, as it was much less active against virus preparations made later in the year. This difference may reflect some uncontrolled part of our technique or some seasonal difference in the virus preparations. (Pierpoint, in collaboration with Harrison, Plant Pathology Department.)

Large-scale Production of Leaf Protein

Progress is being made in establishing leaf-protein production at places other than Rothamsted. A pulper and press sent to Jamaica are being used under the guidance of a committee set up by the Scientific Research Council. A pulper and press are on loan to British Crop Driers (Navenby, Lincs.); the unit is not yet fully installed, but some runs were made in late autumn, and full production should start next spring. The " village unit " mentioned in the 1959 Report was extensively redesigned and now works satisfactorily on 100–200-lb. batches of leaf. Juice is extracted in one operation, and the process takes about an hour and requires 1–2 h.p. The prototype, made for belt drive, will be sent to the National Botanic Gardens (Lucknow), where work on the extraction of leaf protein is about to start. A somewhat simplified machine now being made will be adapted for drive either by a belt or a built-in electric motor.

Our presses, working on the principle of intermittent application of pressure by a platen to a mass of pulp that moves forward as the platen rises, are still satisfactory, but there are defects in intermittent action. We have therefore made a continuous press in which pulp is fed on to the inner surface of a belt that carries it continuously between the belt and a perforated drum. Performance exceeds expectation, and we are now modifying the pulper so that the two machines can be properly integrated. (Davys and Pirie.)

Three new crops, Alsike clover (*Trifolium hybridum*), strawberry clover (*Trifolium fragiferum*) and rape (*Brassica napus*), were grown here for large-scale extraction, and tomato (*Solanum lycopersicum*), comfrey (*Symphytum peregrinum*) and *Tagetes minuta* were got from outside sources. None seems to be preferable to the crops with which we normally work. On the laboratory scale, many species were extracted for the first time during 1960 and 1961: *Melilotus alba, Lupinus luteus, Medicago lupulina, Tropaeolum lobbianum, Atriplex hortensis rubra, Stellaria media, Petroselinum crispum, Lotus corniculatus, Anthyllis vulneraria, Trifolium dubium, Alliaria officinalis, Glechoma hederacea, Anthriscus sylvestris, Heracleum spondylium, Galium aparine, Mercurialis perennis, Tanacetum vulgare, Carduus arvensis, Ranunculus repens, Lamium album, Pennisetum glaucum.* Only the first seven gave very good results, but all were better than the following, which are not recommended: *Onobrychis sativa, Glycine max, Aegopodium podagraria, Arctium lappa, Ranunculus*

ficaria, Chamaenerion angustifolium, Tussilago farfara, Galeopsis tetrahit, Fagopyrum esculentum, Cichorium intybus, Poterium sanguisorba, Buphthalmum sp., Centauraea sp., Lactuca sativa, Oenothera lamarkiana, Calendula officinalis, Chrysanthemum coronarium, Hedysarum coronarium, Campanula rapunculus, Arum maculatum and Salvinia auriculata.

Four varieties of maize (*Zea mays*) were harvested at three dates; striking differences appeared in the yield of extractable protein per acre and the apparent optimal date for harvesting. They need not be discussed now, because the experiment will be repeated next year. One result worth noting, however, is that Caldera 331 photosynthesised at the rate of 40 tons of dry matter per acre per year during the periods 27 July to 16 August. The amino-acid compositions of the twelve batches of protein are being determined by Prof. M. A. Stahmann (Wisconsin), because some earlier results suggested that these may differ with variety and age as well as species; any such differences might explain some disagreement between feeding experiments done on different batches of protein made at different times from the same species.

At the request of the Medical Research Council Tropical Metabolism Unit, Jamaica, some protein labelled with ^{15}N was prepared. ^{15}N, as $K^{15}NO_3$, was fed in nutrient solution to a mildew-resistant variety of wheat, grown in sand in the greenhouse, and cut twice, 9 weeks after sowing and 4 weeks later. First growth yielded 59 g. containing 10% N with 0·7% atom excess of ^{15}N: the excess on the product from the second growth was smaller. This protein was freeze-dried and is now being used in human metabolism experiments. (Byers and Sturrock.)

Overheating leaf protein during drying diminishes its feeding value for animals; experience during the last 10 years suggests that storage also affects it and that the lipids became less readily extracted after a time. Quantitative tests showed that heating affects the lipids; thus, from a batch of clover protein 24·7% of lipid was extracted by a mixture of chloroform and methanol from fresh or freeze-dried material but only 20·7% after drying in an oven at 100°. The effect may be physical, because lipid can be extracted fully from oven-dried protein softened with phenol before extraction. (Shah.)

We prepared less protein than last year because an adequate stock to meet such feeding trials as were foreseen was built up early in the year. The freeze-drier was further improved; its capacity is now 5 kg. of ice per cycle, and the duration of a cycle is shorter. This allows a substantial proportion of the protein from each run to be stored in such a way that it can be reconstituted into a paste very similar to the normal fresh product. Freeze-drying also allows protein to be sent economically to many parts of the world, but it is not envisaged as part of non-experimental production.

Dried protein keeps well with little change in flavour when tightly packed in a sealed container to diminish access of air, but for prolonged storage it is packed in N_2. Various methods of preservation by fermentation in the presence of oatmeal, diastase, malt extract and cabbage (as in sauerkraut) were tried. They have not, so far, been wholly successful, but technique is improving; there is room for

differences of opinion on the merits of the traditional products of fermentation so that criteria of success are uncertain. (Morrison and Pirie.)

The performance of the " village unit " was studied at various stages of its evolution to decide the best weight for the roller and distribution of the bars on it. Many runs were made with the final version, in which the rate of liberation of juice and consumption of power were measured. Protein made in the unit resembles that made by the larger apparatus. (Singh.)

The Potato-root Eelworm Hatching Factor

700 gallons of potato-root diffusate were processed in 1961. Diethylaminoethyl-cellulose failed to give satisfactory recoveries of the hatching factor from potato-root diffusate, so the complex behaviour of the hatching factor during absorption on and desorption from charcoal is being studied to improve the yields.

The purified hatching factor is more difficult to handle in the solid form than was first expected, because it is unstable and hygroscopic. The pale-green copper salt and a cream-coloured calcium salt are both highly active and suitable for analysis. The hatching factor shows no evidence of free carbonyl or hydroxyl groups. Attempts to obtain crystalline derivatives (esters and amides) of the acidic group of the hatching factor failed. The hatching factor gives a positive iodoform reaction and a negative Zimmerman test. Both reactions are given by the CH_3CO-group, but groups readily oxidisable to a CH_3CO-group also give a positive iodoform reaction.

Drastic methods of attack, such as alkali fusion, zinc dust distillation, hydrogen iodide–red phosphorus reduction, etc., proved uninformative, because the products were resinous and not amenable to purification. The products from acid hydrolysis of the hatching factor, however, can be separated into a steam-volatile portion, an ether-extractable acidic fraction, an ether-extractable neutral fraction and a water-soluble residue. Each of these fractions gives a mixture of products when treated with 2 : 4-dinitrophenylhydrazine; five compounds and traces of two others were found in the steam volatile fraction. Progress was also made in separating and purifying the 2 : 4-dinitrophenylhydrazones from the other fractions. The recrystallised derivatives are being characterised by various methods, including X-ray powder photographs (by G. Brown, Pedology Department), a particularly valuable method with the small amounts of material available (0·5–6 mg.).

Experiments with purified material showed that inactivation at room temperature is very rapid (within minutes) at pH $\geqslant$ 11, and more slow at a lower pH. The inactivation is complete and irreversible. The alkali-treated hatching factor has an increased acid function, which previous workers attributed to the opening of a lactone ring. An alternative possibility now being examined is that inactivation and the increased acid function arise from the action of alkali on a readily hydrolysable ester group. Acid hydrolysis after an initial alkaline treatment of the hatching factor appears to give fragments similar to those given by direct acid hydrolysis.

Beet-root eelworm hatching factors

Rape seedlings grown in nutrient solution are one of the most convenient sources of root diffusate with high hatching activity, but hatching curves with such diffusates are abnormal, possibly because they contain inhibitors, and the efficacy of subsequent treatments cannot readily be followed. The diffusate from rape seedlings grown in soil is less active, but gives a normal hatching curve and so was used as starting material to develop isolation procedures. Concentrating the hatching factor in the diffusate by direct evaporation *in vacuo* is more effective in producing active concentrates than is absorption on charcoal. (Clarke.)

Chemical Changes in Self-heated Hay

Studies on the chemical changes in baled wet hay from Great Field, begun in 1960, were extended to include frequent analyses of hay, both baled and stacked at 30% ("wet") and 15% ("dry") moisture content. The wet stack was initially about 12 feet high on a 15-foot-diameter base, and the other about 8 feet high. The maximum temperatures reached were 55° and 27° for the wet and dry bales respectively and 65° and 23° for the wet and dry stacks respectively. The stacks were sampled through pipes penetrating into the interior.

Samples taken at intervals up to 90 days were freeze-dried, stored at −20° and analysed for ash, glucose, total, soluble and steam-volatile nitrogen (distilled at pH 9·5, chiefly ammonia); pH was determined on suspensions of undried samples from the same batches, which were also used for bacterial studies (Soil Microbiology Department) and fungal studies (Plant Pathology Department).

Mould developed unevenly in the wet bales, and the analyses showed corresponding variations: the pH values varied from 5·5 to 6·8, but the glucose content dropped sharply 10 days after baling and remained low. Soluble nitrogen was little in some samples, but more than in the mouldier samples of 1960. Steam-volatile nitrogen increased 5 days after baling and remained high.

The pH of samples from the middle of the stack of wet hay fell from the original 6·2 to 5·3 in 3 days, and the values remained between 4·5 and 5·0 after 18 days; the soluble nitrogen rose sharply after 2 days and remained high, and steam-volatile nitrogen likewise increased. Glucose values were lower than those of dry hay, but higher than those of wet bales. The changes resemble those occurring in silage.

Respiration continued during the 5 days of wilting before baling or stacking and led to loss of dry matter, which was measured by the increase in ash content. After this there was only a slight increase in ash content, although the high temperature maintained shows that metabolism continues, but it does not lead to the formation of a volatile product such as CO_2.

During the 90-day period the changes in the dry bales and stack were small.

Hay from Great Knott 1 baled at 35% moisture content (max. temp. 60°) rapidly developed mould, and its pH was 7·9 ten days

after baling. The samples varied more than those from Great Field (there were different grasses present), and though the analyses gave roughly parallel results, steam-volatile nitrogen increased greatly in only a few samples. (Festenstein in collaboration with Gregory, Plant Pathology Department, and Skinner, Soil Microbiology Department.)

PLANT PATHOLOGY DEPARTMENT

P. H. Gregory

E. W. Buxton returned from secondment to the Central Research Laboratories of the United Fruit Company, Norwood, Mass., and G. A. Salt from secondment as Plant Pathologist to the Sudan Government Service.

The following joined as temporary workers: Dr. Jeanne Dijkstra (Wageningen), Miss R. H. Gregory (Harpenden), Mr. O. Khalifa (Khartoum), Dr. J. B. Kendrick (Riverside, California). A. J. Gibbs and A. C. Hastie were awarded the Ph.D. degree of London University.

G. D. Heathcote visited British North Borneo on behalf of the Colonial Development Corporation to investigate a virus disease in abaca plantations at Tawau. B. Kassanis visited Paris and Versailles to discuss plant tissue-culture techniques. D. H. Lapwood visited institutes in Wageningen and the Max-Planck Institute, Cologne, in connection with work on blight-resistant potatoes. I. Macfarlane was awarded a W. K. Kellogg Foundation Fellowship and spent four months at the University of California, Berkeley.

Viruses and Virus Diseases

Properties of reaggregated tobacco mosaic virus protein

Intact tobacco mosaic virus resists proteolytic enzymes such as pepsin, trypsin and papain, but these hydrolyse the disaggregated protein produced when the virus is disrupted by alkali. This is now shown to happen because the different walls of the protein sub-units of the virus differ in their susceptibility to attack: the walls normally exposed to the environment are resistant, whereas those concealed within the virus particle are susceptible but inaccessible to the enzymes. When the pH of protein solution is lowered the protein sub-units aggregate by a process comparable to crystallisation. The protein sub-units fit into a regular pattern similar to that in intact virus particles or in reconstituted virus containing nucleic acid. All such particles resist attack by the proteolytic enzymes. (A. Kleczkowski.)

Tobacco necrosis viruses

Five isolates of tobacco necrosis virus (TNV) were studied; they were serologically related but differed in their antigenic composition and several physical and biological properties. Two obtained from the " Rothamsted culture " had many antigenic groups in common with bean stipple streak and cucumber TNV, and these four all induced the multiplication of the satellite virus of the " Rothamsted culture " of TNV, which alone does not multiply detectably. The fifth virus, isolated from the roots of a *Datura stramonium* plant,

had only a few antigenic groups in common with the others and does not induce the multiplication of the satellite virus. Bean stipple streak became systemic in French bean and cucumber TNV in cucumber, but the others remained localised in all the species of plants tested.

Studies of inactivation *in vitro* at different temperatures showed that preparations of TNV contained two fractions, which inactivated according to first-order kinetics but at greatly different rates. The ratio of the two fractions differed at different temperatures. The more resistant fraction was about 10% of the preparation at 50° C., and the proportion decreased with increasing temperature.

An unstable variant was isolated from one of the TNV strains. Sap from leaves infected with it gave fewer lesions when inoculated to bean or tobacco plants than did leaf extracts made with water-saturated phenol, in contrast to its parent virus, with which sap gave more lesions than extracts made in water-saturated phenol. The results suggest that the unstable variant may occur in leaves mainly in the form of nucleic acid, which loses its infectivity when the leaves are macerated.

All the isolates except cucumber TNV were often found in considerable amounts in the roots of normal-looking plants grown in the glasshouse. In some species of plants virus was also detected in the leaves. Natural infection of roots by TNV was prevented by adding a fungicide to the soil during the winter but not during summer. (Kassanis and Babos.)

Potato virus X

The multiplication of potato virus X (PVX) in tobacco (White Burley) is considerably influenced by changes of temperature. The relative concentrations in inoculated leaves, measured serologically by precipitation tests, were 512 at 25° C., 64 at 28° C., 16 at 31° C., and the virus was not detected at 34° C. In systemically infected leaves the relative concentrations were 1,024 at 25° C., 128 at 28° C. and virus was not detected at 31° C. or 34° C. However, in plants inoculated simultaneously with potato virus Y (PVY), the relative concentrations of PVX in the systemically infected leaves were 4,096 at 25° C., 1,024 at 28° C., 128 at 31° C. and the virus was not detected at 34° C. The effect of PVY in increasing the concentration of PVX at 25° C., 28° C. and 31° C. was confirmed by infectivity tests. Some other viruses than PVY made virus X multiply detectably at 31° C.; in systemically infected leaves the relative concentration of PVX was 64 with tobacco mosaic virus and 256 with henbane mosaic virus and with yellow cucumber mosaic virus. These viruses multiply at 31° C., and inoculation with tobacco severe-etch virus, a strain of cucumber mosaic virus or potato aucuba mosaic virus, which do not multiply at 31° C., failed to stimulate the multiplication of PVX. (R. Close.)

Potato aucuba mosaic virus (*PAMV*)

In summer and autumn this virus reached a high concentration (precipitin end point $\frac{1}{2^{\frac{1}{5}6}}$) 14 days after inoculation to a White Burley tobacco leaf, and the concentration was the same whether

it was alone or in mixed infections with potato virus Y (PVY). Aphids (10 per test plant) did not transmit PAMV to tobacco or pepper from plants infected by it alone, but did readily from plants infected with PVY. Serological tests for PAMV and PVY showed that some of the tobacco test plants were infected with PAMV alone, some with both viruses and some with PVY alone. PAMV was transmitted only when aphids fed for less than 1½ hours on infected plants. Exposing infected leaves to ultra-violet radiation prevented aphids from becoming infective. (R. Close.)

Soil-borne viruses

Grapevine viruses. Viruses from Portuguese grapevines with diseases of the yellow mosaic type or the fanleaf type were transmitted by inoculation of sap to thirty herbaceous species in five plant families. The two types of isolate produced similar symptoms in most hosts, but could usually be differentiated in *Chenopodium amaranticolor.* When transmitted back to grapevine, by grafting with infected *C. amaranticolor*, an isolate from a grapevine with fanleaf caused fanleaf symptoms, and an isolate from a grapevine with yellow mosaic caused yellow mosaic symptoms. Serological tests showed that the viruses causing these two distinct diseases in grapevines share many antigenic groups. Both viruses are distantly related to the type strain of arabis mosaic virus. (Dias and Harrison.)

Difficulty in transmitting viruses from grapevines to herbaceous plants by sap inoculation can largely be attributed to inactivation at the low pH value of sap from grape leaves. An inhibitor of infection that was active in undiluted grape-leaf sap at pH 7 was less important. (Dias.)

Nematode vectors. Scottish strains of tomato black ring virus are transmitted by *Longidorus elongatus*, and can be differentiated serologically from English strains. *L. attenuatus* was associated with a disease outbreak caused by an English strain and, when extracted from the soil and placed on healthy plants, it transmitted this strain.

Raspberry ringspot virus, too, occurs in England and Scotland in strains that can be distinguished serologically. *L. macrosoma* occurred at disease outbreaks in raspberry and blackberry in England, and it transmitted the English strain of the virus in glasshouse experiments. (Harrison.)

Control measures. Nematicide experiments, made in collaboration with J. E. Peachey (Nematology Department), showed that methyl bromide and " D.D " both control the virus vector *Xiphinema diversicaudatum*, and that these chemicals have promise for preventing the spread of arabis mosaic virus. Other chemicals, and varying the method of application, are being tested. (Harrison.)

Structure of small polyhedral virus particles

Internal structure can be seen in electron micrographs of one group of viruses with similar properties (turnip yellow mosaic, wild cucumber mosaic and a virus recently isolated from cocoa), but not in other groups. This failure cannot be explained by lack of

resolving power, for pictures showing resolution of the 1·0-mμ order can easily be obtained, and it seems unlikely that the sub-units of all the other viruses studied are smaller than 2–4 mμ in diameter. Lack of contrast appears to be mainly responsible, for when structure is seen in turnip yellow mosaic virus it is often visible only in pictures taken under conditions providing maximum contrast, and it disappears when the current in the objective lens is raised to provide the sharpest possible image. Attempts are now being made to improve this state of affairs by altering the staining techniques, but it is not yet possible to exploit to the full the potentialities of particle morphology as a basis of virus classification. However, we already have pictures showing that groups of viruses with similar biological and physical properties also have particles that resemble each other in the electron microscope, and the visible similarities and differences are often big enough for a trained observer to place an unknown virus preparation in the correct group with some confidence. (Nixon, Gibbs and Woods.)

A new virus from cocoa

When completed this work will describe the symptomatology, host range, transmission, purification and properties of a previously undescribed virus isolated from cocoa. The particles resemble those of turnip yellow mosaic virus and wild cucumber mosaic virus; preparations contain two components, one of which seems to be free from nucleic acid and non-infective. (Nixon, Gibbs and Woods, in collaboration with R. H. Kenten, West African Cocoa Research Institute, Tafo, Ghana.)

Clover yellow mosaic virus (CYMV)

This virus has as yet been found in clovers only on the west coast of North America. Electron micrographs of the virus, prepared by the cut-leaf method from infected *Gomphrena globosa*, showed that its particles are flexuous rods 520–530 mμ long. Serological tests by us and by Dr. M. J. Pratt (Vancouver) failed to show any relationship between CYMV and potato aucuba mosaic (580 mμ), and CYMV was not transmitted by *Acyrthosiphon pisum* from plants infected with CYMV alone or in combination with pea mosaic virus or bean yellow mosaic virus. (Gibbs and Woods.)

Carrot motley dwarf

This disease was widespread in England and ruined most carrot crops sown in April or May, but was less damaging in crops sown later. It is spread by the aphid *Cavariella aegopodiae*, which was caught on the sticky trap at Woburn between 8 May and 28 July. The maximum catch, 609/sq. ft. of trapping surface, was in the week 17 to 26 June. Attempts to control the disease and to measure yield losses at Woburn did not fully succeed, but spraying three times with " Metasystox " starting 5 June, increased the yield of roots from a crop sown on 16 May from 3·5 to 6·6 tons/acre. Spraying three times starting 27 May had less effect with a crop sown on 13 April, increasing yield from 6·1 to only 7·1 tons/acre, probably because the crop was exposed for so much longer than the later-

sown one to invasion by winged aphids. The spray checked the population of wingless aphids breeding in the crowns of the carrots, but had less effect on incoming winged ones, which, arriving a week after spraying, could feed long enough on the carrots to deposit young.

Transmission tests in the glasshouse show that motley dwarf is caused by the simultaneous infection of carrots by two viruses, red-leaf and mottle. Red-leaf virus is transmitted by *C. aegopodiae*, but not by manual inoculation with sap from diseased plants; it has not been transmitted to any plant outside the *Umbelliferae*. Mottle virus is transmitted by manual inoculation of sap, has hosts outside the *Umbelliferae* and causes characteristic symptoms in *Nicotiana clevelandii* and *Chenopodium* spp. It is transmitted by aphids only from plants also infected with red-leaf virus, but from these can be transmitted by aphids to plants insusceptible to red-leaf. Both viruses seem to be retained equally long by aphids, and both were still transmitted by aphids 8 days after they had left infected plants.

Carrot could not be infected by sap inoculation with mottle virus, but another umbelliferous plant, coriander, was. Transmission from carrot and other hosts of mottle virus were achieved by inoculation with sap, and with leaf extracts made with phenol–water mixtures. The infectivity of these extracts was probably conferred by virus nucleic acid, for it was destroyed by pancreatic ribonuclease which does not inactivate the virus in sap. Sap from plants infected with mottle virus contains specific spherical particles, diameter about 30 mμ.

About a quarter of the carrot seedlings raised from seed set by infected plants have reddened cotyledons or first true leaves. These seem to contain red-leaf but not mottle virus. Symptoms in seedlings that inherit the virus through the seed are mild and ephemeral, but virus transmitted from them by aphids to other seedlings often caused more severe and more lasting symptoms.

A virus obtained by Dr. R. Cammack from a mottled parsnip by sap inoculation caused symptoms in *N. clevelandii* resembling those caused by carrot mottle virus. However, it differed by being transmitted by sap inoculation to carrot and celery. This virus was not transmitted by *C. aegopodiae*, but in tests direct from mottled field parsnips the aphid transmitted virus to carrot and caused symptoms similar to, but not identical with, motley dwarf. Like carrots with motley dwarf, these parsnips probably contained two viruses, for the virus transmitted from them by inoculation of sap was not afterwards transmitted by aphids. (M. A. Watson and Serjeant.)

Wheat striate mosaic

Another vector was identified for wheat striate mosaic in *Delphacodes dubia*; after feeding for 8 days on infected plants, more than 70% of the individuals tested infected healthy plants on which they fed. (Kisimoto.)

We previously reported an abnormality in the eggs of *Delphacodes pellucida* infected with wheat striate mosaic virus. The role of the virus in this abnormality, however, becomes doubtful from

the discovery that inbreeding develops similar abnormalities in insects that are free from the virus. Thus when four females were brought in from the open, the eggs of three were all normal, and only a few eggs laid by the fourth failed to hatch. However, brother-to-sister matings among their progeny produced females whose eggs were 31% abnormal and failed to hatch; females produced by outbreeding laid only 4% abnormal eggs. Further inbreeding caused 48% abnormality in the F2 generation, compared with only 3% in outbred F2 females. Of the F2 inbred females, 6% were sterile or produced all abnormal eggs, and about 30% had fewer than 1 in 5 abnormal eggs. (Kisimoto.)

Poa annua plants in Great Field were found infected with wheat striate mosaic. Plants sent by Miss K. Ikaheimo from Finland also contained a virus apparently identical with ours. Plants brought by Dr. J. T. Slykhuis from Egypt, and thought by him to be infected with a virus like wheat striate mosaic that might have *Sogatella nigerenis* as a vector, yielded no virus when fed on by either *S. nigerenis* or *D. pellucida*. Neither *S. nigerenis* nor *Euscelis plebeja* transmitted wheat striate mosaic. (M. A. Watson.)

Adult *D. pellucida* became infective when juice from plants with striate mosaic was injected into their thorax at 5° C. There was an incubation period of from 10 to 23 days before the injected leafhoppers transmitted and about one-third of them survived long enough to transmit. Infective hopper extracts could be obtained at dilutions equivalent to one adult hopper (weight 3 mg.) per millilitre. Plant extracts diluted 1 : 2 infected hoppers, but higher dilutions did not. (Serjeant.)

Other grass and cereal viruses

Of twenty samples of cereals from different parts of England, Ireland and Scotland tested for viruses, eighteen, including the Irish samples, were infected. Sixteen had viruses of the barley yellow dwarf type transmitted by *Rhopalosiphum padi*, *Sitobium avenae* and *S. fragariae*, and two of the type transmitted by the *Sitobium* spp. and *Metopolophium dirhodum* only (*Sitobium* viruses).

Of seven samples of grasses tested, two contained cocksfoot streak, and one striate mosaic virus.

Barley yellow dwarf was recovered by *Ceruraphis eriophori* from sedges, *Carex trichocarpa* or *C. laxiflora*, sent by Dr. Eastop of the Natural History Museum. Both are new records for the virus.

The *Sitobium*-transmitted yellow dwarf viruses were recovered by *Sitobium fragariae* and less often by *Metopolophium dirhodum* when fed through membranes on sap from infected plants. *R. padi* fed in this way did not transmit these or any viruses; nor did the *Sitobium* spp. transmit the *padi*-transmitted viruses, although they do from plants. (M. A. Watson and Serjeant.)

Virus diseases of beans (Vicia faba)

The incidence of virus diseases was recorded in field beans at four of the spring-bean variety trials of the National Institute of Agricultural Botany, Cambridge, and also at Rothamsted, where seven varieties were grown.

Beans were infected later in northern than in southern Britain,

and, in the north, only pea leaf-roll virus (PLRV) was common. There was a consistent difference between varieties in the incidence of PLRV but not of pea enation mosaic or pea mosaic viruses. At all sites the incidence was greater in the tick bean Herz Freya than in others and was often least in Minor; in horse beans incidence was greatest in Granton and often least in Strubes. At Rothamsted the primary infestation of all four varieties named above and three others by *Aphis fabae* and *Acyrthosiphon pisum* was similar, and was not correlated with the incidence of PLRV. Glasshouse experiments, in which young plants of these varieties were similarly infested with *A. pisum* taken from PLRV-infected plants, showed that Herz Freya was more susceptible than Minor, and Granton more than Strubes. (Gibbs, L. R. Taylor, Entomology Department, and Mr. D. T. A. Aldrich (N.I.A.B.).)

Fungi and Fungus Diseases

Surveys of cereal foot and root rots, 1937–60

Wheat grown in the six-course rotation experiment (potatoes, rye, sugar beet, barley, clover, wheat) at Rothamsted had an average of 34% straws with eyespot (19% with severe lesions) in the period 1937–60. The proportion of straws infected varied in different years from 2 to 99%, those with severe lesions from 1 to 81%. This variation depended both on weather and on the amount of fungus surviving from preceding cereal crops. The steady rise in severe infections in the living wheat from a mean of 7% in the first 6-year period to 31% in the fourth is attributed to a gradual increase in infected crop residues during the experiment. The small incidence at the beginning probably reflects the fact that, on different blocks, the site had been free from wheat for 6–11 years before the experiment began.

The fungus (*Cercosporella herpotrichoides*) is helped to survive the 5-year interval between wheat crops in the six-course experiment by the cereal crops grown in alternate years. Barley, about as susceptible as wheat, is sown in spring, which allows less time for the fungus to develop; rye, less susceptible, but sown in autumn, develops about as much eyespot as barley. In the 9 years in which barley and rye were surveyed (1952–60) each had an average of 8% straws infected, but only 2% had severe lesions, as compared with 45% straws infected, 27% severely, in wheat during the same period. Self-sown barley in the following clover crop in some years also helped the fungus to survive.

Wheat lodged on some plots in 10 of the 30 years of the experiment (1931–60). It was severe only on plots which carried at least 51 cwt. straw/acre or when at least a third of the straws had severe eyespot lesions; when 44–81% were severely infected, some plots lodged with as little as 38–40 cwt. straw/acre.

The lowest yield of wheat grain was obtained in 1958, when straw yield was near the average (of 44·9 cwt./acre), but 81% of the straws had severe eyespot lesions, and the whole crop was lodged. Mean grain yield (30 years) was 28·5 cwt./acre, and the highest yield, 41·1 cwt./acre, was obtained in 1944, when eyespot was slight and there was no lodging or other recognised inhibiting factor.

The mean number of wheat straws per acre (1942–60) showed an annual variation between 1,106 and 2,091 in thousands per acre. Thirty-eight % of the annual variation in straw yield was accounted for by variation in the number of straws alone, the inclusion of eyespot having no additional effect. Only 18% of the variation in grain yield was accounted for by the number of straws alone, but when the depressing effect of severe eyespot was included together they accounted for 48% of the variation. (Glynne.)

Uncommon wheat diseases

Gibellina cerealis. This rare and interesting pathogen on wheat is recorded in Britain only on Hoos field alternate wheat and fallow experiment. It was more common in 1961 than since it was first recorded in 1935, though it is unlikely to have materially affected yield. As in several other years, it was more common after 3 years than after 1 year under fallow.

Melanospora damnosa, in association with *Fusarium culmorum*, was found on oats in Sussex, on wheat, barley and oats at Rothamsted, on wheat near Hitchin and on barley in Hants. It had previously been reported in Sardinia and Tunisia, but this appears to be the first record on cereals in Britain. (Glynne and Dr. F. Joan Moore, Ministry of Agriculture, Fisheries and Food.)

Effect of date of sowing of winter wheat in relation to previous crops

Unusually heavy rain prevented sowing during October, November and December in the final year of the series of experiments on date of sowing of winter wheat. After two successive non-cereal crops (beans–potatoes) the mean grain yields of Cappelle wheat sown on 29 September (D1), 19 January (D2) and 15 February (D3) were 41·2, 48·5, 45·7 cwt./acre. Eyespot and take-all were negligible, and lodging was severe only on D1, which, on 22 July, was 13% lodged at N1 (0·6 cwt. nitrogen/acre) and 75% lodged at N2 (1·1 cwt. nitrogen/acre). After a wheat crop the mean yields were 28·5, 34·8, 37·7 cwt./acre for D1, D2, D3, respectively. Take-all (*Ophiobolus graminis*) and eyespot (*Cercosporella herpotrichoides*) were both decreased by late sowing; in July D1, D2, D3 had 65, 28, 18% straws with take-all and 18, 10, 5% with severe eyespot. There was little lodging. The responses to additional nitrogen (N2–N1) differed greatly on the two experiments; the responses on D1, D2, D3 were −3·4, +4·4, +0·1 cwt. grain/acre after potatoes and +12·2, +9·8, +5·0 cwt./acre after wheat. (Slope and Glynne.)

Cereal–beans rotation

The summarised results of the wheat yields in the second and third years of the rotations on all three series of this experiment are:

Previous crops	Grain yield (cwt./acre) Second-year crop: winter wheat			% straws with take-all		
	1958	1959	1960	1958	1959	1960
W	17·4	37·4	25·2	89	11	84
B	19·3	31·9	30·2	82	41	82
sW	17·3	37·5	21·2	89	29	85
O	29·2 *	41·9	47·5	8	2	10

* Adjusted yield, severe bird damage.

Previous crops		Grain yield (cwt./acre) Third-year crop: spring wheat			% straws with take-all		
		1959	1960	1961	1959	1960	1961
W	W	32·0	28·7	32·7	12	26	20
sW	W	32·4	26·4	33·4	8	36	27
O	W	29·2	24·7	32·3	20	62	33
W	O	32·0	31·3	36·7	3	2	5

W = winter wheat; sW = spring wheat; B = spring barley; O = spring oats.

Take-all was the most prevalent disease, and weeds flourished only in crops severely stunted by disease. *O. graminis* var. *avenae* has not been recorded at Rothamsted, and oats therefore behave as a non-susceptible crop in this experiment. In the years when take-all was severe (1958, 1960) winter wheat after oats yielded 80% more grain than wheat after wheat, but only 12% more when take-all was not severe (1959). In the years 1959–61 take-all was less severe on spring wheat than on winter wheat; consequently, the effect of a previous oat crop on yield of spring wheat was much smaller. However, in 1958 a spring wheat crop in this experiment had 75% straws with take-all and yielded only 11·8 cwt. grain/acre.

The fourth-year crop (Cappelle wheat, sown 23 January on Series II) had 58, 76, 71, 66, 72 and 7% straws with take-all in July after the crop sequences W W sW, B W B, sW W sW, O W sW, W O sW and W O Beans respectively, and yielded 29·3, 22·0, 27·6, 23·7, 25·2 and 43·4 cwt. grain/acre. (Slope.)

Effect of chlorinated hydrocarbons on take-all

In pot experiments mixing aldrin (A), dieldrin (D), chlordane (C) and heptachlor (H) with soil before planting decreased infection of wheat inoculated by burying agar cultures of *O. graminis* 2½ inches below the soil surface. Cappelle wheat, sown 31 January, had 40·4% crown roots infected in untreated controls on 28 March; adding A, C, H, at 0·005 g. active ingredient/pot (each pot contained 2·3 kg. soil) brought down the percentage roots infected to 36·3, 17·8, 29·3 respectively, and at 0·05 g./pot brought them to 11·4, 0·0, 1·7. An experiment sown with Koga II wheat on 28 April gave similar results. On 4 July 91·6% of the crown roots of untreated control plants were infected, but only 13·8, 50·1 and 2·7% of roots of plants grown in soil treated with 0·05 g. active ingredient of A, D, H respectively. Although the chlorinated hydrocarbons were used at high rates in these experiments (0·05 g./pot is equivalent to 18 lb./acre on an area basis), the amount of inoculum was much greater than would occur naturally, and the results seemed to justify field experiments. On 3 October Cappelle wheat was sown with 100 or 300 lb./acre of a 2% granular formulation of heptachlor. On untreated control plots on 2 November 23·6% plants had take-all; this was brought down to 19·0, 14·8 and 13·2% by heptachlor broadcast, combine-drilled or side-placed respectively; the percentage infection was similar for both rates of application of heptachlor. This decrease in primary infection is unlikely to be important unless the heptachlor also decreases later development of the disease. (Slope, with Last and Bardner, Insecticides Department.)

Take-all and eyespot on Broadbalk

In July take-all was again less severe on Broadbalk than on the cereal–beans experiment, although early infection was similar on the two sites. In the 4th successive wheat crop on Broadbalk plot 7, 11% of plants were infected on 1 May and 26% on 17 July. In contrast, on the 5th wheat crop in the cereal–beans experiment 16% plants were infected on 14 April and 93% on 18 July. Routine sampling on Broadbalk in 1961 showed that on plots 2B, 3 and 7, the 1st, 2nd, 3rd, 4th and 10th consecutive wheat crops drilled on 19 January, after 1 year fallow, had respectively: 9, 49, 46, 46 and 31% straws with eyespot, of which 3, 24, 28 and 12% had severe lesions: 0, 9, 16, 19 and 9% straws had take-all on the roots. For the 5th consecutive year there was less eyespot in the continuous wheat (Section 1A) than in the 2nd, 3rd and 4th wheat crops after a 1-year fallow. (Cox.)

Brown Foot-rot (Fusarium *spp.*)

In 1959 and 1960 yields of spring wheat and responses to nitrogen were very small in some experiments with nitrogenous fertilisers at Woburn: the low yields were associated with high incidence of Brown Foot-rot. In July 1961 it was apparent that yields and responses to nitrogen would be small in an experiment testing rates and methods of application of nitrogen. This experiment was sampled on 11 August and the following incidence of Brown Foot-rot recorded: nil N 10%; 0·40 cwt. N/acre 39%; 0·77 cwt. N/acre 70%. The incidence of foot-rot was the same whether the nitrogen was broadcast as sulphate of ammonia or combine-drilled as part of a compound fertiliser. The mean grain yields were: nil N 9·4; 0·4 N 12·2; 0·77 N 11·1 cwt./acre. In each of the 3 years observations indicated that the poor growth and yield of wheat and the high incidence of foot-rot were associated with poor soil structure. (Slope.)

Cephalosporium *stripe*

The *Cephalosporium* isolated from wheat last year was confirmed as *C. gramineum* Nisik., Mats. & Yam. by Mr. J. J. Elphick of the Commonwealth Mycological Institute. In March Koga II wheat seedlings (three-leaf stage) were inoculated with this isolate by dipping their roots into a suspension of spores and mycelium before replanting; 92% of these inoculated plants developed typical symptoms of *Cephalosporium* stripe during April, and *C. gramineum* was easily re-isolated from them. Naturally infected plants were collected during May and June from the area of Broadbalk field where the disease was first found last year, but none could be found in other parts of the field. One infected plant was found in Deacons field. The disease has now been found in four fields at Rothamsted, but is too rare to be important. However, naturally infected and inoculated plants yield little or no grain, and should the disease become common, it could be extremely serious. (Slope.)

Yellow rust (Puccinia glumarum)

In a wheat variety trial on Deacons field the percentage of flag leaves infected by *P. glumarum* on 28 July was: Viking (S.80) 45,

Professor Marchal nil, Cappelle nil. The infection developed late, and the variety Viking yielded as much as Professor Marchal and more than Cappelle. (Slope.)

Effect of herbicides on take-all in wheat

Severe attacks of take-all on commercial farms are sometimes attributed to the use of herbicides of the hormone type, but as all the crop is usually sprayed, there is no direct evidence that the herbicide has affected disease incidence or severity. The apparent correlation between herbicide and disease need mean only that weedy fields are those with a history of cereal cropping, and are therefore liable to have take-all.

On Great Field I none of three herbicides affected the incidence of take-all in Cappelle wheat sown on infested land. During May and June numbers of infected crown roots were similar with all treatments, and in July the percentage straws severely affected was 37 in the unsprayed plots, 38 sprayed with 2:4-D, 30 with CMPP and 40 with MCPA/TBA. Spraying with herbicides had no significant effects on yields, which were small with the high incidence of take-all, or on height of straw or percentage of tail corn. The lack of effect in this experiment contrasts with an experiment on Highfield in 1957, when spraying Koga II wheat with CMPP doubled the percentage of severely infected straws; the increase then was from 14 to 26% on land where the experiment followed wheat and from 8 to 16% where it followed oats. (Salt.)

Control of potato blight

For the first time potato blight was recorded in a tuber in a growing crop before it was noted on the haulm of this or any other nearby crop. The event happened while sampling an experiment on the Rothamsted Farm on 8 August, when a young King Edward tuber was found infected on a plant otherwise free from symptoms.

Dry weather delayed the " outbreak " stage (0·1% foliage destroyed) until 15 September. As a result, the planned schedule of protective and haulm-killing sprays could not be completed on an experiment designed to determine the best date for " burning off ". Instead, on 21 September, when blight had destroyed only 1% of the foliage, selected plots were sprayed with concentrated sulphuric acid to see whether yield was decreased by spraying with copper in a year almost free from blight. Some plots were not sprayed with acid, to measure the effects of later blight spread on plants with and without protective fungicides.

Although on 21 September the foliage was greener on the unsprayed plots than on those sprayed with copper, all those killed with acid at this time yielded similarly (13·57 and 13·86 tons/acre with two and three sprays with copper oxychloride and 14·12 without copper). Yields of plots not sprayed with copper were the same whether destroyed by acid on 21 September (14·12 tons/acre) or allowed to die on their own (13·95), but plots sprayed three times with copper yielded 14·98 tons/acre when allowed to grow to maturity, compared with 13·86 when killed with acid on 21 September. However, examining samples of lifted tubers showed that this apparent gain from copper sprays and loss from acid spray was

largely illusory. From the acid-sprayed plots only 0·5% of the tubers were infected, whereas 10% of the others were. These samples point the need for further work on the best time to kill the haulms with acid; they show that, with such a susceptible variety as King Edward, even in a year when blight was generally regarded as unimportant, increased yields from copper sprays can be more than offset by tuber infections, which destroyed more than a ton per acre unless the haulms were killed by acid while still growing. (Hirst and Stedman.)

Apple scab

Spore trapping continued during the spring in one Bramley's Seedling orchard (Wisbech H, ascospore dose 20, see Hirst & Stedman, *Ann. appl. Biol.* **49**, 290, 1961), but despite the exceptionally wet, late summer of 1960 ascospores were rare. Measurements of leaf survival and ascospore productivity were continued in several orchards.

Three investigations begun in previous years were extended. Catches of ascospores from heavily infected Bramley's Seedling leaves placed close to and level with the orifice of a Hirst spore trap ½ m. above ground level represented up to 27,000/cu. m. of air. Because the source was locally so intense, it was possible to detect small releases during periods of dew deposition and to confirm the claim by Miller and Waggoner (*Phytopathology*, **48**, 416–419, 1958) that some release occurred in fair weather, although in our observations it always followed nights with rain or dew. In these tests and a series where batches of leaves were repeatedly wetted in the wind tunnel, many more ascospores were liberated by day than by night. From other work it now seems unlikely that this results from single effects of light, temperature, atmospheric turbulence or the interval between wettings. There is evidence that the day-time prevalence, often noticed in orchards, results from the combined effects of repeated wetting and different responses of ascospore liberation and maturation at low night temperatures.

Previous measurements of the ascospore productivity of dead leaf samples from orchards suggested that sulphate of ammonia applied as a fertiliser before bud-burst might be decreasing the number of ascospores liberated. (Strong solutions of sodium nitrate or ammonium sulphate were found to have this effect by Keitt and others during their early work on eradicant fungicides.) In two tests in 1961, 3 or 6 cwt./acre of sulphate of ammonia given 3 weeks before bud-burst decreased the number of ascospores liberated 2 weeks later by more than 90%. No rain fell during these 2 weeks, but if the effect is confirmed in other weather, applications of sulphate of ammonia should be timed to make best use of their fungicidal and nutritive actions. (Hirst and Stedman.)

Raindrop collision with plant surfaces as a cause of dry spore liberation

Raindrops trap and deposit many fungus spores suspended in air, cause the discharge of some, by wetting the fructifications containing them, and disperse others in splash droplets when they collide with spore-bearing surfaces. Spore traps often show brief

increases in concentration at the onset of rain, and tests showed that water drops falling at their terminal velocity can disperse many spores. When the target was *Puccinia graminis* on wheat straws some of the spores were borne in splash droplets, but trapping on slides half coated with naphthol green B in gelatin and half with " Vaseline " showed that most were dry (see *Trans. Brit. mycol. Soc.* **44**, 138–139, 1961). Further tests showed that spores are dispersed, with varying ease, from plants infected with: *Cladosporium herbarum, Alternaria* sp., *Ustilago tritici, Pseudoperonospora humuli, Phytophthora infestans*, conidia of *Venturia inaequalis, Erysiphe* sp., *Puccinia glumarum* and *P. obtegens*.

The number of spores released depended not only on the form and position in which they were presented but also on the size of the drop and the number which had fallen previously. No doubt many spores were released by the collisions shaking the plants and small glass beads were as effective as water in dispersing *P. graminis*. When *Lycopodium* spores were deposited evenly over the surface of a 5-inch-diameter steel block weighing 8½ lb., beads suspended many fewer spores than water drops of either the same weight or diameter. None of these impacts shook the block, so it seems possible that dispersal was caused by rapid air movement ahead of the radially spreading drop during the millisecond after collision. (Hirst and Stedman.)

Soil activity of Phytophthora infestans

The tuber-slice technique for assessing *P. infestans* in soil (*Rep. Rothamst. exp. Sta.* for 1960, p. 124) was calibrated using black fen soil from Littleport, Cambs. The results differ by a factor of about 10 from those obtained with a Rothamsted soil. To infect 50% of the octants needed about 50 sporangia per slice, compared with 500 for Rothamsted soil, and 78% (or, after applying the multiple infection transformation, 150 infections/100 octants) were caused by 110 sporangia/slice, compared with about 1,000 with Rothamsted soil. Calibration is thus necessary with each soil tested.

Many antibiotics were found to be toxic to *P. infestans*, but pimaricin, polymixin and penicillin at concentrations of 100, 50 and 50 p.p.m. respectively have little effect on growth. Attempts to use these three antibiotics together, to check bacterial and fungal contamination when isolating the fungus from soil, failed because they did not control bacteria.

Soil samples were taken from around inoculated seed tubers of different varieties at intervals between 10 May and 4 August. Tuber-slice tests were positive from 18 May (about 3 weeks after planting) until 14 July, by when most tubers were rotting. Irrigation had little effect on infectivity. Ulster Ensign gave the most tuber-slice infections, followed by Duke of York, King Edward, Pentland Ace and Majestic, in order of decreasing numbers. Sporangiophores and sporangia were seen on tubers of Ulster Ensign and King Edward on several occasions. Spore production by inoculated tubers of Ulster Ensign was examined in the field and laboratory. Tubers were lifted at intervals from 6 to 21 days after inoculation in the field and incubated at 15° C. in a humid chamber for 24 hours. Sporangia were then washed off and their numbers

estimated. Maximum spore production occurred 8–13 days after inoculation, when up to 40,000 sporangia/tuber were produced. Maximum spore concentrations estimated to be up to 2,300 spores/c.c. soil were found around these tubers 9–18 days after inoculation. *P. infestans* spread from an inoculated tuber to healthy tubers of Ulster Ensign where tubers grew close together.

Estimation of spore profiles below the crest of the ridge, in Majestic potatoes, was difficult in 1961, because blight appeared late and destroyed less than half the foliage before the plants died naturally. Sporangia were most abundant in the surface soil on 13 September, when the concentration rose from an estimated 560 sporangia/c.c. to 2,100 sporangia/c.c. after 0·77 inch rain. This coincided with an increase from 45 to 1,600 sporangia/c.c. at 2 inches, 0 to 1,600 at 4 inches, 0 to 670 at 6 inches and from 30 to 1,070 at 8 inches. Infectivity declined afterwards as the haulm died, but infectivity was still detectable nearly 3 weeks after a crop of Up-to-Date, 95% of whose haulm was destroyed by *P. infestans*, had been burnt off with concentrated sulphuric acid (BOV). (J. Lacey.)

Haulm and tuber resistance to blight (Phytophthora infestans)

The value of the 1961 field experiments on the nature of resistance of different varieties was decreased because dry weather early in the season retarded development of the crop and because the disease, although introduced in August as soon as weather was favourable, failed to become epidemic until early September. Thus, in a field experiment where ten varieties (selected because they varied greatly in haulm susceptibility in laboratory tests) were planted in small (twenty-plant) replicated plots, the haulm destruction of only four later-maturing varieties could be studied in detail by leaf tagging. Voran haulm was half defoliated (50% marked leaflets dead) by blight 6 days, Libertas 11 days and Zeeburger 14 days later than Majestic. The delay in Voran and Libertas was explained by the slower rate leaves were destroyed after infection, whereas in Zeeburger this was combined with a delay in the initial infection of the leaves (50% leaflets infected 9 days later than in Majestic). Sporulation differed on the different varieties, and the mean width of the sporing annulus measured in the field for 6 days was 4·4, 1·7, 1·6 and 1·1 mm. for Majestic, Zeeburger, Voran and Libertas, respectively.

Umaerus (*Sverig. Utsädesfören. Tidskr.*, **70**, 59, 1960) reported that the minimum infection period differed between varieties, for the susceptible Anna it was 3 hours and for the resistant Ackersegen 8 hours. To investigate this, experiments were done with varieties of differing susceptibility. Leaflets of detached leaves in boxes were inoculated with droplets of sporangial suspension, and after 1, 3, 5, 7, 10 or 24 hours' incubation at 15° C., leaves were removed, the inoculation droplets dried and the incubation continued at a low relative humidity until lesions appeared (the petioles were dipping in water). Ackersegen behaved like the susceptible Bintje, but Pimpernel differed. Although some Pimpernel leaves, like Bintje, became infected in 3–5 hours, some took 24 hours, whereas all Bintje were infected within 7 hours.

Continuing the study, begun in 1960, of tuber infection in the

field, the two susceptible varieties Up-to-Date (UD) and King Edward (KE) were compared with two more resistant varieties, Arran Viking (AV) and Majestic (MJ), in plots arranged in a 4 × 4 Latin square. Sampling methods were as described in 1960. The detection of blight and the detailed inspection of tubers were made difficult on UD and MJ because of the high proportion of tubers severely affected by scab (*Actinomyces scabies*); tubers of KE and especially AV were much less affected, but unfortunately there were few tubers infected with blight on KE, because of the rapid natural death of the haulm early in the epidemic. The first blighted tubers were found on 12 September on UD, KE and AV (with about 5% blight on haulm), and 1 week later on MJ (blight developed more slowly on the haulm of this variety). The number of infected tubers from later samples increased after periods of rain, except in MJ, which had few infected tubers. Infections on about half the AV tubers (recorded as newly infected on lifting) failed to develop on further incubation; this also happened with MJ and agrees with laboratory results reported in 1960. Unlike 1960, most infections on UD were on the body of tubers, and few infections occurred at the heel end of any variety.

Laboratory experiments using wound-free tubers were continued, and the relative susceptibility of fifteen varieties was assessed on the number of tubers successfully infected and the amount of rotting after 14 days at 15° C. Populair, Robijn and Pimpernel proved most resistant, and Ulster Ensign, Duke of York and Bintje most susceptible. The resistance of Majestic showed clearly, but Arran Viking proved more susceptible in these tests than expected from field experiments. (Lapwood.)

Fusarium *wilt*

The *Fusarium* state of an isolate of *Nectria haematococca* was crossed with several cultures of wilt-inducing *Fusarium oxysporum* to seek genetic relationships between them. Further crosses involving *F. solani* were made to see whether Fusaria that caused wilt could be mated with any that caused foot-rot. Heterokaryons (colonies with hyphae containing nuclei of different genetic origins) were separately established between isolates of *F. oxysporum* f. *pisi*, *F. oxysporum* f. *lycopersici*, *F. oxysporum* f. *cubense*, *F. solani* f. *pisi*, *F. solani* f. *phaseoli* and the *Fusarium* state of the *Nectria*. The first three cause wilt of pea, tomato and banana respectively, and never cause foot-rot; the other two cause foot-rot of pea and French bean, and never cause wilt. Heterokaryons were also made between all the isolates of *F. oxysporum*, but none could be made directly between *F. oxysporum* and *F. solani*.

Using markers induced by ultra-violet irradiation and the specific pathogenicity towards different hosts showed that heterokaryons between each isolate and the *Nectria* led to genetic recombination during ascospore formation. With electrical and mechanical micromanipulation, 931 single ascospores were isolated from crosses and analysed genetically. Most characteristics were isolated in new genetic combinations, but the ability to cause foot-rot was never found recombined with ability to cause wilt. This suggests that genes governing these abilities may be allelic or very closely

linked. The ability to form perithecia was not always inherited through ascospores of the crosses, even though the *Nectria* itself was 100% homothallic. This situation, already recorded in *Aspergillus* spp., might indicate either a cytoplasmic control of perithecial formation or the presence of a dominant " non-perithecial " gene in the Fusaria used in these experiments.

The fact that the *F. oxysporum* isolates did not cross with those of *F. solani*, yet each separately and easily crossed with the *Nectria*, suggests a close phylogenetic relationship between the two. Their well-defined difference in ability to rot or wilt plants seems the only reliable means of telling them apart, for physical characteristics such as spore shape are not always sufficiently consistent for definite identification. (Buxton.)

Control of Fusarium *wilt*

Flaked chitin has been reported to deter *Fusarium* wilt (*United Fruit Company Reports*, 1960–61). It was used on a *Fusarium*-infested area in Essex and in experiments on pea wilt in the glasshouse. In the field a 7 × 7 Latin-square design, with treatments of soil at six concentrations of chitin, showed that applying it at 8 oz./7-foot row prevented pea wilt in variety Onward. De-acetylated chitin had the same effect as pure chitin.

In glasshouse tests, adding chitin to infested soils 4 or more weeks before introducing pea seedlings prevented wilt. Dilution plates of soils, to which chitin had been added 1–8 weeks previously, revealed a decrease in populations of *Fusarium* as the association of soils and chitin increased. Using a selective agar medium containing colloidal chitin, soil-borne actinomycetes were isolated from treated soils. As the number of actinomycetes increased in soils containing chitin, the numbers of Fusaria decreased. Tests show that many of these actinomycetes antagonised at least five different *Fusarium* strains, including three physiologic races. This probable mechanism of the mode of action of chitin in preventing wilt is being studied in relation to other factors that are already known to operate in the host root surface zone. (Buxton.)

Banana fruit rots

Serious losses are incurred in transporting bananas from Jamaica to Britain. Infection can occur either in the field, during shipment or in ripening rooms in this country. Fourteen different species of fungi were isolated from fruit variety " Lacatan "; most frequent were *Gloeosporium musarum*, *Thielaviopsis basicola* and *Fusarium roseum*. *Deightoniella*, *Botryodiplodia* and *Pestalotia* were common. Seventy-eight isolates were tested for pathogenicity. *Gloeosporium* and *Fusarium* caused most damage and, unlike *Thielaviopsis* and *Pestalotia*, they caused lesions on unwounded fruit. All seventy-eight isolates caused more damage at 80° F. (ripening temperature) than at 58° F. (refrigeration temperature in ships' holds during the 9-day voyage). Some, notably *Thielaviopsis*, caused considerable damage at 58° F. Sources of infection are banana trash in the field, decaying florets on stems during shipment and the air of ships' holds and ripening rooms (*United Fruit Company Report*, August 1960). (Buxton.)

Sitka seedling diseases

To serve as a background for future work, soils from five forest nurseries were analysed in detail using a modified dilution-plate method. Fungi isolated are arranged in five groups—*Penicillium* spp., *Phycomycetes*, *Sphaeropsidales*, *Fusarium* spp. and others, including *Paecilomyces* spp., *Cephalosporium* spp., *Chaetomium* spp. and less commonly *Wardomyces anomala* Brooks and Hansf. and *Emericellopsis minima* Stolk.

At Bagley Wood and Ringwood the dominant species of *Penicillium* were *P. daleae* Zal. and *P. janthinellum* Biourge, respectively. At two Kennington nurseries, Old and Extension, *P. daleae* Zal. and *P. restrictum* Gilm. and Abb. were equally abundant, whereas at Wareham, *P. melinii* Thom., *P. spinulosum* Thom. and *P. restrictum* Gilm. and Abb. predominated. Many phycomycetes were isolated, including species of *Mortierella*, *Zygorhynchus* and *Absidia*. *Mortierella macrocystis* Gams. was found in great numbers, but only at Bagley Wood; *M. vinacea* Dixon-Stewart and *M. ramanniana* (Moeller) Linnemann were numerous at Ringwood.

Phoma spp., and *Coniothyrium* spp., of the Sphaeropsidales, were common and *Pyrenochaeta* spp. occasional. The ratios of the numbers of isolates of *Phoma* to *Coniothyrium* were greater at Kennington than at Ringwood. *Fusarium oxysporum* Schlecht. ex Fr., *F. solani* (Mart.) Sacc., *F. sambucinum* Fuckel, *F. avenaceum* (Fr.) Sacc. and *F. merismoides* Corda were isolated at all sites, with *F. sambucinum* Fuckel particularly common at Kennington Extension.

The two groups of fungi most often isolated from diseased Sitka seedlings, without using chemical surface sterilants, were rarely isolated from soil. *Cylindrocarpon radicicola* Wollenweber was the fungus most frequently isolated at Kennington Old and Ringwood. Next was a group of four species of *Pythium*, including *P. ultimum* Trow and *P. irregulare* Buisman, but the two most abundant, RR 493 and RR 494, seem not to have been described before. (Ram Reddy and Last.)

Mycofloral succession in hay

Grass from Great Field I was again cut for experiments on moulding of hay, but the product was very unevenly dried, and the mean water content lower than aimed at. The practice of crushing cut grass to aid drying of the stalks needs constant tedding to get even drying. The moist hay (average water content approximately 30%) and dry hay (approximately 15%) were both baled and stacked. The moist bales reached a temperature maximum of 55° C.; the most spores, recorded visually on the eighth day after baling, were 21 million moulds and 42 million bacteria and actinomycete spores per g. dry weight of hay. Using the Andersen sampler, 2,900 colonies of moulds per g. were obtained in culture, mainly *Aspergillus fumigatus*, *Mucor pussilus*, *Absidia ramosa* and *Aspergillus nidulans*, all of which grew at 24° and 40° C. (*Paecilomyces* developed after 3 weeks). Few bacteria grew at the lower temperature, but actinomycetes grew at all three incubation temperatures: 1,200 colonies per g. at 24° C., 1,000 at 40° C. and 3,200 at 60° C. The bales of this batch were not particularly rich in actinomycetes, but

had abundant thermophilic moulds. The stack of this batch of moist hay (which was sampled through a horizontal tube in the stack) differed in appearance from the bales; it was dark, sour-smelling and brittle. Micro-organisms developed more slowly, the peak concentration of spores being counted visually on the 16th day, with 5 million mould spores per g. (mainly *Humicola* (*Monotospora*) *lanuginosus*) and 37 million bacteria and actinomycete spores per g. In culture the few bacteria mostly developed at the lower incubation temperatures, and the actinomycetes mainly at the higher temperatures (e.g., 4,800 per g. at 60° C.).

In the dry hay temperatures rose to maxima of only 23° C. in the bales and 24° C. in the stack, the microbial content in both remaining more or less stationary, with only *Aspergillus glaucus* increasing appreciably; the maximum in the bales of total mould spores was 0·07 million per g. and in the stack 0·1 million per g. (except for one count of 6 million spores per g. from a sample on the 9th day). The bacteria and actinomycetes were very variable, but never exceeded 1 million per g. in either bales or stack.

In an attempt to obtain more evenly dried moist hay, grass from Great Knott I was baled at an average water content of 35%. The wetter patches of this heated to 60° C. and moulded. A maximum of 184 million bacteria and actinomycetes per g. was counted visually on the 10th day after baling. A few bacteria grew at all temperatures, and numerous actinomycetes were obtained in culture: 360 per g. at 24° C., 1,300 at 40° C. and 10,600 at 60° C. A maximum of 40 million mould spores per g. were counted on the 11th day, mainly *Mucor pusillus*, with some *Humicola lanuginosus*. The usual thermophilic species grew at 40° C., with *Paecilomyces* developing after 2 weeks. The dry hay (20% moisture content) heated to a maximum of 35° C., and produced *Aspergillus glaucus* spores with a maximum of 35 million per g. on the 11th day. On the same day the maximum of 2 million bacteria and actinomycetes per g. was counted.

Although the hay in 1961 was variable, it confirms the conclusion from the two previous years that the microbial content of hay is determined mainly by the moisture content at baling. (Gregory and M. E. Lacey, with Festenstein, Biochemistry Department, and Skinner, Soil Microbiology Department.)

Occurrence of Pithomyces chartarum *in Britain*

This fungus is a saprophytic mould, known to be widely distributed in the tropics and sub-tropics. In New Zealand it produces the toxin, sporidesmin, which causes "facial eczema" of sheep. While examining Hirst trap slides, exposed at Imperial College Field Station in 1958, six spores of *Pithomyces chartarum* were seen, and O. J. Stedman observed one spore on a slide exposed at Rothamsted in September 1960. In an attempt to find the fungus in the field a whirling-arm air-sampler was used to sample air in several areas in Surrey and Berkshire during September 1961. Spores were caught in all the areas tested, the most at Virginia Water, where 426 spores/cu. m. of air were detected and where the fungus was found growing on the remains of mown grass (mainly *Holcus lanatus*). Isolations were obtained from the air by exposing Petri dishes in the Andersen

sampler at the site, and from the dried grass by the standard method used for mouldy hay. This is believed to be the first collection of the fungus in Europe. It is not yet known whether the British strains of the fungus produce sporidesmin. (Gregory and M. E. Lacey.)

NEMATOLOGY DEPARTMENT

F. G. W. Jones

Mary T. Franklin and J. B. Goodey were awarded the degree D.Sc. (Lond.) and H. R. Wallace D.Sc. (Liverpool). Seven members of the department and four visiting workers attended the Sixth International Nematology Symposium in Ghent, at which C. C. Doncaster showed films on predators of soil nematodes and on feeding mechanisms. J. B. Goodey visited the Laboratory for Phytopathological Research, Wageningen, and the Bulb Research Station, Lisse. Mr. G. N. Rao (India) joined the department to work for two years on the assessment of nematicides in field trials, and J. M. Webster was appointed in place of J. J. Hesling, who left in December 1960. Mr. W. C. Clark returned to New Zealand in July and became his country's first plant nematologist. R. D. Winslow left in August to join the staff of the Department of Agriculture, Queen's University, Belfast, where he is first holder of the post of nematologist in Northern Ireland.

Systematics and Bionomics

The revised text of *Soil and Freshwater Nematodes* went to the publisher in October. It contains some 500 pages, about 300 figures, half of which are new, and 87 tabular keys for the identification of nematodes down to genera.

Work on *Radopholus* shows that it falls into two groups of species. A joint paper with Dr. M. Luc (Côte d'Ivoire) proposes a new genus, *Hirschmannia*, to include *R. lavabri*, *R. gracilis*, *R. oryzae* and *R. mucronatus*. The new genus is distinguished by its high, hemispherical head not offset from the body, by the ventral overlap of oesophagus and intestine, and by the mucronate tail. The five new species of *Longidorus* mentioned last year were described as *L. leptocephalus*, *L. attenuatus*, *L. goodeyi*, *L. caespiticola* and *L. macrosoma*, and the neotype of *L. elongatus* (de Man, 1876) Thorne & Swanger 1936 from the type locality in Holland was redescribed. Careful examination of populations of *Trichodorus* in connection with work on transmission of soil-borne viruses (with Harrison, Plant Pathology Department) showed the presence of an undescribed species together with *T. primitivus*, the vector of tobacco rattle virus. An undescribed species of *Paratylenchus* was also found and will be described. *Aphelenchoides limberi* Steiner 1936 from mushroom compost readily fed and reproduced on mushroom hyphae on malt agar. It also reproduced on *Botrytis cinerea*. Males were not seen; the shape of the female tail terminus varied greatly. Another species of *Aphelenchoides*, close to *A. hunti* Steiner 1935, also reproduced on cultures of *B. cinerea*. Both nematode and fungus were isolated from rotting gardenia buds. Other species which also reproduced readily on *Botrytis cinerea* were *Aphelenchoides composticola*, *A. dactylocercus*, *A. saprophilus*, *A.*

subtenuis, *Aphelenchus avenae*, *Ditylenchus myceliophagus* and *Paraphelenchus myceliophthorus*. Six species of fungus-eating nematodes were tested on cultures of the dry-rot fungus, *Merulius lacrymans*, and another wood-rotting fungus, but none reproduced or affected the mycelia adversely. (Goodey and Hooper.)

To study variation in the posterior cuticular pattern of females, on which identification is based, the root-knot nematodes *Meloidogyne arenaria*, *M. javanica* and *M. incognita* were cultured on tomato roots in nutrient foam-agar in plastic bags. The method is time consuming and sometimes fails, but is better than pot culture, because it eliminates cross infection. Inoculations were made with eggs and larvae from selected females and mounts prepared from parents and female offspring of the first and second generations. Infested roots were treated with different fixatives at different temperatures, but there was little difference between mounts, except in the ease with which phasmids could be seen or unwanted tissues cleared away from the cuticle. Better mounts were obtained with lactophenol than with formalin. When adequate collections of patterns have been accumulated they will be used to show the variability between individuals of the same clone. Males were not extracted from the agar-foam cultures, although a few were seen in stained roots. As in *M. arenaria* and *M. incognita*, reproduction in *M. javanica* appears mainly parthenogenetic. (Franklin.)

Visitors from India, Ireland, Japan, Persia, Poland, Switzerland and Yugoslavia were taught to identify nematodes and to extract them from soil by various techniques. Many samples were received for diagnosis and many specimens for identification. *Citrus* spp. from Tripoli were infested with *Tylenchulus semipenetrans*. *Meloidogyne javanica* was received from Tripoli and Egypt and *M. hapla* from Tripoli. (Franklin, Goodey, Hooper.)

Short lengths of film were made of fungi that trap nematodes, of the amoeba *Theratromyxa* that engulfs larvae and of the small zoospore of an Archimycete which attacks *Heterodera* larvae. Zoospores gather in clusters on some part of the nematode body and the cuticle swells. The attacked nematode gradually ceases to move, is penetrated and flask-shaped zoosporangia are formed in it from which zoospores are liberated. (Doncaster.)

Samples taken in February and May from Broadbalk had similar nematode populations after 3, 4 and 9 years continuous wheat. In the wheat crops grown in 1961 the May counts, as expected, were smaller than the February ones, but in the 1961 fallow plots numbers were well maintained in May, and many genera of Tylenchida were more plentiful than in February.

In the Woburn irrigation experiment the effects of irrigation were more pronounced on the grass plots than in the wet season of 1960. In August *Paratylenchus* spp. and *Pratylenchus* spp. were more numerous on watered plots, whereas *Aphelenchus* sp. was more numerous on the unwatered plots. To measure the depth distribution of nematodes in Rothamsted flinty loam and Woburn sand, pits were dug and a post-hole borer was used. Although nematodes were most numerous in the top foot of soil, they were not confined to this layer. Spear-bearing and plant-parasitic nematodes penetrated more deeply than other forms. (Winslow.)

Stem and Bulb Eelworm, *Ditylenchus dipsaci*

Next to the cyst-forming nematodes, the various biological races of stem and bulb eelworm are the most important nematode pests in Great Britain. Because they attack leaves and stems rather than roots, infection occurs in the soil surface and the nematodes tend to be carried above ground, partly by their own movements and partly by elongation of stems. However, the vertical distribution of *D. dipsaci* in soil of an infested oat plot was similar to that of other nematodes, except that, after rain, the numbers of *D. dipsaci* increase at the surface of the soil and can survive drying in an atmosphere of 50% relative humidity for 34 days, equivalent to a soil moisture tension of pF6 in a dry soil. When infested plants were wetted many *D. dipsaci* emerged. This nematode moved farther in a sandy loam than in a clay soil, but oat seedlings were invaded at similar rates in a clay loam and a sandy loam. Because *D. dipsaci* moves little in clay soils, any tendency it has to move downwards from the infection site at the soil surface is inhibited. Thus, higher concentrations persist on the surface of clay than of sandy soils, and the infestation rate, as well as lateral spread in the surface run-off, is enhanced. Also in similar weather clay soils retain surface moisture longer than sandy soils, so clay soils probably provide more opportunity for the nematodes to move and invade the host plant.

Studies of the directional movements of *D. dipsaci* in gradients of physical stimuli showed that: (*a*) in a temperature gradient of 2°–30° over 15 cm., *D. dipsaci* aggregates at about 10°; (*b*) in a moisture gradient the nematodes aggregate at the end with a high moisture content; (*c*) in a particle-size gradient they collect in the fine particles at one end of the gradient, and that (*d*) the orientation of *D. dipsaci* is unaffected by light, gravity or water percolation, but passive directional movement may occur under the last two stimuli. Orientation in temperature and moisture gradients cannot be explained in terms of a simple orthokinetic response, but aggregation in a particle-size gradient can. (Wallace and Greet.)

The speed with which *D. dipsaci* from oats moves in sand is related to the moisture characteristic where the pore diameter permits movement. In sands of particle size 150–250 μ, 250–500 μ and 500–1,000 μ maximum invasion of oats occurred at the flex point of the moisture characteristic and was greatest in the 250–500 μ sand. For three sands examined, the movement and invasion curves were closely correlated. Movement in sand depended on the forces holding water between the soil particles, and was independent of the osmotic pressure of solutes dissolved in the soil water until their concentration caused incipient plasmolysis of the nematodes. The concentration required to kill *D. dipsaci* approximated to that causing permanent wilting of plants, and so it is unlikely that soil additives such as sugars that act only osmotically would be effective nematicides, although they have been claimed to be. So much would be needed to raise the osmotic pressure of soil water, of which there are some 200 tons/acre, that plants would fail to grow and the soil microfauna would be greatly affected.

Fourth-stage larvae of *D. dipsaci* were attracted to oat seedlings

growing aseptically on an agar film by a water-soluble and dialysable substance that exudes from the seedling. Most larvae were attracted to the root–stem junction of the plant, though some were attracted to the roots, especially the root tips. Larvae moving across an agar surface increased their rate of turning (klinokinesis) near to the plant, and accumulation at the plant appeared to involve a dynamic equilibrium. The attractant was non-specific; it was produced by non-host plants and resistant varieties, and also attracted larvae of the lucerne race. Larvae were also attracted to oat seedlings growing in sand, when the moisture content of the sand allowed nematodes to move.

The number of pre-adult larvae that invaded plants of the susceptible oat variety Sun II and the resistant Manod was not significantly different. Invasion of the susceptible variety, however, led to dissolution of the middle lamellae, hypertrophy and cell digestion, and the larvae matured and multiplied rapidly, whereas there was little cell separation and hypertrophy in the resistant variety, where sexual maturity was delayed and multiplication was greatly slowed. Adult males and females from the resistant variety had shorter bodies and gonads. The length of the female gonad increased rapidly and heterogonically compared with the body during the late fourth stage, especially immediately after the moult, in individuals from both susceptible and resistant varieties. Throughout their growth the length of the body (x) and the length of the gonad (y) were related by the equation $y = bx^k$, where b and k are constants with different values before and after the final moult. (Blake.)

Larvae in dried infected leaves containing the narcissus strain of *D. dipsaci* survived storage at 5° better than at 10° or 20°. Pre-adult larvae revived after 18 months' storage were less infective than pre-adults revived after only 2 months. The population peak in bulbs was slightly earlier than the peak in leaves, and fell almost to zero as bulbs died. In the leaf the population level decreased and then remained constant as the leaf dried and larvae became inactive as eelworm wool. Eelworms migrated into the soil continuously in numbers proportional to the numbers in the bulb. All stages moved into the soil, mostly through the bulb base, and, because the population of the bulb declined as the disease progressed, there was no mass migration when it died. (Webster.)

Biology of *Tylenchorhynchus macrurus*

Tylenchorhynchus macrurus is being used as a test organism in an attempt to get as complete a picture as possible of the ecology of one species of nematode. It occurs in two size forms, of which only the larger has been described. The taxonomy and size distribution of both are being studied in populations from Rothamsted and in Holland. The body length of the two does not overlap, and they may prove to be distinct species. *T. macrurus* orientates in a moisture gradient, and its movement is related to soil moisture and temperature much as in *Heterodera*, *Ditylenchus* and *Aphelenchoides*, which suggests that the basic responses of nematode species of widely different habits follow a similar pattern. The Cartesian

diver technique showed that oxygen consumption by *T. macrurus* is independent of size and sex, but is proportional to the surface area of the nematode rather than to its length or volume. (Wallace and Greet.)

Movement of Nematodes

An analysis of the movement of different nematodes from different habitats includes studies of their wave formation in thick and thin water films and between solid particles. Ciné films showed that the active plant nematodes *Ditylenchus*, *Aphelenchoides* and *Anguina* differ greatly from the soil forms such as *Heterodera* and *Tylenchorhynchus*. The results are being used to test mathematical interpretations of undulatory movement. The active plant nematodes, because of their high wave frequency (wave/minute), can swim in deep water, and therefore move into thick water films on the surface of plants and soil. In thin films and between solid particles the wave frequency is *decreased*, and symmetrical waves of long wavelength and short amplitude are produced. The soil nematodes, by contrast, form incomplete and unco-ordinated waves in deep water, and this, combined with a low wave frequency, precludes any swimming in water films and prevents them from escaping from the soil. In thin films and between particles the wave frequency is *increased* and symmetrical, and co-ordinated waves are produced, which permits efficient movement. Free-living nematodes, e.g., *Rhabditis*, *Diplogaster*, have a locomotion similar to the active parasites, suggesting that there are ecological relationships between the two groups. That both of the genera *Aphelenchoides* and *Ditylenchus* contain free-living species supports this hypothesis. (Doncaster and Wallace.)

Cyst-forming Nematodes *Heterodera* spp.

Population studies

Experiments on pea-root eelworm in microplots are in progress at Rothamsted and at Yaxley in collaboration with the Pea Growing Research Organisation. At Yaxley in 1960 the effect of growing seven varieties of pea was compared with broad bean, field bean and fallow in soil previously mixed and containing on average 25 cysts 100 g. and 10 eggs/g. The pea varieties were harvested at the time appropriate for canning, freezing or packeting, and increases in population were roughly proportional to the length of vegetative-life, the least increase being under the quick-maturing variety Meteor (58 cysts/100 g. and 52 eggs/g.) and the greatest under Perfected Freezer (187 cysts/100 g. and 200 eggs/g.). Field bean, harvested dry, raised the population greatly (131 cysts/100 g., 150 eggs/g.), but broad bean harvested in the green-pod stage was comparable with Meteor pea (66 cysts/100 g., 71 eggs/g.). At Yaxley in 1961 and at Rothamsted in 1960 one variety of pea was grown on all microplots (Big Ben at Yaxley and Onward at Rothamsted). At Yaxley there were significant differences in weight of tops, weight of peas, straw length and leaf-stipule areas after the 1960 treatments. The height of the plants and their leaf area declined significantly as

the eelworm populations of the plots increased, but there was no relationship between yield of tops and peas and the eelworm population, suggesting that yield was influenced more by other factors. At Rothamsted in plots filled with heavy soil, height of plants, weight of tops and weight of peas decreased significantly as the eelworm population increased. The same was true for plots filled with light soil, but the level of significance was less. On neither type of soil were initial and final populations correlated. The eelworm multiplied more in slightly than in highly infested plots, and the population declined in some of the most heavily infested plots. In consequence, the population level was less variable after growing one variety of peas, and tended towards a ceiling of about 100 eggs/g. soil. In 1961 at Rothamsted the plots were divided into two groups, those with 50–100 and those with 100–150 eggs/g. soil and peas, variety Onward, were again sown. Sulphate of ammonia at 0, 10·5 and 21 lb. N/acre was applied to plots on the light soil and 0 and 21 lb. N/acre on the heavy soil. On the light soil nitrogen was without effect, and all plots failed completely from eelworm attack. On the heavy soil nitrogen increased yield significance by 5% on the less heavily infested plots but not on the highly infested plots. (Jones and Shepherd.)

Hatching and hatching factors

As part of the work on hatching factors, large quantities of potato-root diffusate were produced from potted potato plants and small quantities from tomatoes and rape kale. Progress was made in the final stages of characterising the hatching factor for potato-root eelworm (see Clarke, Biochemistry Dept.). Characterisation of the factors for beet eelworm, of which there appear to be several, are still in an early stage.

The method of bioassay in use, devised by Dr. D. W. Fenwick, is to put replicate batches of cysts in water and in dilutions ($\frac{1}{1}$, $\frac{1}{4}$, $\frac{1}{16}$, $\frac{1}{64}$, $\frac{1}{256}$, $\frac{1}{1024}$) of a stock of diffusate and to count the larvae that hatch after 3 weeks at 24°. The hatch is then plotted against dilution to give a standard dilution curve, with which the unknown solutions prepared in the Biochemistry Department are compared after making a suitable series of dilutions. Because cysts and diffusate vary, a standard curve must be included in each weekly set of assays. The method is laborious and time-consuming, and efforts are being made to find ways of making it less so. A simple pipette was devised to produce batches of cysts, and attempts are being made to estimate hatch by absorptiometry, the object being to avoid counting cysts and larvae except as checks on technique. Preliminary results are promising, but assay of purified factors by the dilution technique is beset with many difficulties, the chief of which, apart from variability, is the absence of a sharp end-point to hatching-factor activity. When hatch is plotted against dilution the curve is asymptotic to the water hatch, and the arbitrary end-point found by drawing a straight line through the points to cut the water hatch is not always satisfactory, though no better method of fixing an end-point has been devised. (Gander and Jones.)

Continued attempts to make *H. göttingiana* hatch in the laboratory failed, but active larvae were successfully released by soaking

in 5% sodium hypochlorate for about 30 minutes, a treatment that partly dissolved the cyst walls. Soaking cysts in trypsin for 24 hours was ineffective. Keeping cysts in darkness during their removal from soil and throughout the hatching test did not give an increased hatch. The possibility that larvae, in the process of hatching, produce a substance which affects the egg membrane was considered. Cysts of *H. rostochiensis* were placed in potato-root diffusate for 2 days and then transferred to water in which many larvae hatched and were removed by sieving. Unstimulated cysts of *H. rostochiensis* and *H. göttingiana* were then placed in this fluid, but there was no hatch from either species.

Hatching in *H. schachtii* has been observed for the first time. As with *Meloidogyne* spp., *H. rostochiensis* and *H. cruciferae*, the larva can move inside the egg just before hatching. Observations began 15 minutes before the larva was liberated, when the stylet was already moving. The larva moved its head slowly back and forth in an arc around the end of the egg, making rhythmical stylet probes at a rate of 40 minute for some time, but about 5 minutes before hatching the rate increased to 90 minute. Eventually the head emerged through a hole about the same as the width of the larva, and the rest of the body squeezed out through the aperture, which did not enlarge.

Various artificial hatching agents have been found for *H. schachtii*, several of them having an activity equivalent to or greater than average beet-root diffusate. Some of these substances are oxazine, mono-azo, diphenyl-methane and anthraquinone dyes, and others, including one found by Dr. C. Winner in Germany, are acridines. Such substances may be useful in unravelling the chemical properties associated with hatching activity. (Shepherd.)

Nematicides

Recommended doses of soil fumigants were applied in autumn 1960 or spring 1961 to small plots of land on Long Mead, Woburn, heavily infested with potato-root eelworm. Their effects on yield were determined by taking a crop of Majestic potatoes, and their effects on the survival of the eelworm by growing Majestic potato plants in pots containing samples of soil from the variously treated plots and counting the number of larvae that invaded a given weight of root. The untreated plots yielded 0·2 tons of ware tubers acre and had 5,834 larvae g. of root. Plots treated with methyl bromide in autumn yielded over 11 tons of ware acre and had only 144 larvae g. of root. Autumn treatments of " Vapam " or " Mylone " gave yields of 8 tons acre and root infestations of about 500 larvae g. of root. Spring treatments with " Trapex " (methyl isothiocyanate) and " Vapam " gave yields varying from 8 to 6 tons acre, but had lower root infestations of about 100 larvae g. of root. Plots treated with " D.D " or " Tridipam " yielded only 3 tons acre, though they decreased the root invasion by 85%. A reasonable yield of potatoes, however, apparently demands bringing the invasion well below the 900 larvae g. of root achieved by these treatments.

Counts of cysts after the potatoes had been harvested did not

reflect the beneficial effects of the fumigants on yield. The residual larvae on the treated plots multiplied to give populations equal to, or greater than, those in the untreated plots, where the poor root system of the heavily infested plants prevented an increase proportional to that where the plants grew vigorously. The benefit then is only for the immediately succeeding potato crop, and the cost is too great to apply to field crops, where adequate crop rotation can control potato-root eelworm. However, these results have their practical use where tomatoes are grown under glass in infested soil.

A preliminary trial in co-operation with Mr. C. A. Collingwood of the National Agricultural Advisory Service showed that tomato plants growing on "Trapex"-injected plots compared well with those on adjacent steamed areas and were much better than on untreated plots. Root invasion was decreased by 93% in treated plots: estimates of kill from root invasion agreed with those from hatching tests. Applying the fumigant to the soil surface was unpleasant and ineffective. Although treated only 34 days before planting at a soil temperature of 9° C., the tomato plants were unharmed. (Peachey.)

The differences in kill estimated from root invasion and hatching tests, the relative merits of both methods and their relationship to initial and final cyst densities are being studied. (Rao.)

Soil fumigants were applied at recommended doses to strawberry-growing land in Pembrokeshire infested with *Xiphinema diversicaudatum*. "D.D" increased the yield by 50% in 1960 and decreased the incidence of arabis mosaic virus. "Vapam" and "Mylone" failed, probably because they did not penetrate. In 1961, after treatment with "D.D" at 800 lb. acre or methyl bromide at 1 lb. 50 sq. ft., no living *Xiphinema* was found. "D.D" at 400 lb./acre killed 97%, and "Trapex" 54%. The methyl bromide penetrated to 12 inches, reaching a CTP of 100 mg./l./hr. Ammonia-nitrogen, determined by Gasser, Chemistry Department, increased after all treatments, reaching 63 p.p.m. for methyl bromide, a tenfold rise over controls. The direct effect of this nitrogen on yields will be considered in 1962. (Peachey and Harrison, Plant Pathology Department.)

Winter fumigation of Woburn ley–arable plots with "Vapam" killed 90% of the plant-parasitic nematodes. (Peachey.)

INSECTICIDES AND FUNGICIDES DEPARTMENT

C. Potter

F. T. Last left to become head of the Mycology and Bacteriology Section of the Glasshouse Crops Research Institute. Mrs. Evelyn Piall also left and was replaced by D. W. Eveling. J. H. Stevenson was appointed to work on pyrethrum.

A. J. Arnold returned after three years at the West African Cocoa Research Institute, and Mr. A. A. Buadu came from the Institute for technical training.

Insecticides

The action of organophosphorus insecticides

Effect of organophosphorus poisoning on the free amino acids in houseflies. Preliminary tests showed that the free amino-acid content of houseflies (*Musca domestica*) was changed by treatment with diazinon and some other organophosphorus poisons. The largest effect was a decrease in alanine, but two other ninhydrin reacting substances, tentatively identified as glutamic and aspartic acids, were also affected. A technique was developed to estimate more quantitatively the free amino acids in houseflies and used to study the effect of diazinon on the content of amino acids of strains of houseflies susceptible and resistant to this poison.

Although some evidence was obtained that the free amino-acid content differs with the strain, this is difficult to establish, because the content in male houseflies depends on age and nutrition. There was no evidence that free amino-acid contents were related with resistance. With all the strains tested, doses well in excess of the LD95 of diazinon decrease some free amino acids; 24 hours after treatment, α-alanine and proline fall by about half, aspartic and glutamic acid by less. The amount of β-alanine also sometimes falls. The amino-acid content is affected 2 hours after treatment, at about the same time as the insects first show symptoms of poisoning. Insects were also treated with a smaller dose (approx. LD50) and examined 16–18 hours later; the amino-acid status of surviving insects was unchanged, whereas in those that die it changed in much the same way as in those treated with larger doses of the poison. The fall in amino-acid content is not related to the amount of poison applied, but to its toxicity; an amount that affects a susceptible strain may have to be increased by 40 times to affect a resistant strain.

Because all but one of the amino acids affected by organophosphorus poisoning are closely linked to the tricarboxylic acid cycle through related keto-acids, the effect of inhibitors of the tricarboxylic acid cycle (fluor-acetic acid) and respiration (cyanide) were examined. Both inhibitors increased the free alanine. Fluor-

acetic acid decreased the free proline, an effect known to be produced by DDT and organophosphorus compounds. The increase in alanine caused by respiratory poisons would follow the accumulation of pyruvic acid resulting from disturbance to the respiratory cycle. Conversely, a decrease in alanine might reflect either increased activity of the respiratory cycle or a decrease in the amount of pyruvic acid because of blocking of either fat or carbohydrate metabolism. (Lord and Solly.)

Inhibition of cholinesterases in the central nervous system of Musca domestica *L. by diazinon.* After poisoning with diazinon, inhibition of cholinesterase in the central nervous system is localised in certain areas, which include the peripheral regions of the supra-oesophageal and thoracic ganglia, and, more generally, the sub-oesophageal ganglion and the lamina ganglionaris. In contrast to these areas where inhibition is almost complete, the neuropile or synaptic regions of these ganglia retained much enzyme activity 24 hours after a lethal dose had been applied. Lethal doses rarely inhibited cholinesterase throughout the nervous system. Hence, if death is caused by the inhibition of cholinesterase in the nervous system it is because of local inhibition and not generalised inhibition, as has often been supposed. (Molloy.)

Cholinesterase in the peripheral nervous system of Musca domestica *and* Periplaneta americana. The existence of a cholinergic system of neuromuscular transmission in insects is in doubt, partly because the essential components of the system, acetyl choline, choline acetylase and cholinesterase, have not been demonstrated in insect muscle, either biochemically or histochemically. A search was started for cholinesterase in frozen sections of cold-acetone-fixed insect nerve-muscle preparations, using a modification of the thiocholine method of Koelle and Friedenwald. An enzyme that hydrolyses acetyl thiocholine iodide and is inhibited by treatment with eserine, and so is probably specific cholinesterase, occurs in the nerves and finer nerve branches in the leg muscle of the cockroach (*P. americana*), but the amount is very small compared with that in the central nervous system.

Prolonged incubation in the substrate (18 hours at 25° and pH 5·8) shows that this enzyme may also occur in the cockroach leg-muscle fibres themselves, as distinct from the nervous elements in the muscle, particularly in the fibres of the "white" or fast-contracting muscle. However, the technique is not yet good enough to show which parts of the fibre contain the enzyme.

The fine nerve branches in the indirect flight muscle of houseflies are only faintly stained for cholinesterase after 24-hour incubation with the substrate and, unlike *P. americana*, enzyme was not found in the muscle tissue itself.

Preliminary experiments with diazinon-poisoned houseflies showed almost no stain in nerve-muscle preparations, indicating almost complete inhibition of cholinesterase. However, there is so little enzyme present in the unpoisoned fly that it is difficult to assess the degree of inhibition. (Molloy.)

Inhibition of cholinesterase of susceptible and resistant strains of housefly, Musca domestica, *by "diazoxon".* Earlier work showed that to produce a given amount of inhibition of cholinesterase in

the central nervous system, resistant strains of fly required larger doses of diazinon applied externally than did susceptible strains. Experiments were done to see whether the isolated ganglia of the central nervous system of the resistant strain differed from those of the susceptible strain with respect to inhibition of their cholinesterase. " Diazoxon ", the active analogue of diazinon, was used. The thoracic ganglia from susceptible and resistant houseflies were dissected out and incubated with various concentrations of " diazoxon " in 0·13*M*-NaCl for 30 minutes, when cholinesterase inhibition was assessed. Histochemical examination by a modification of the Koelle technique (Gomori, 1952) showed no difference between the strains, and this was confirmed when the ganglia were macerated after treatment, and cholinesterase inhibition assessed in the Warburg. Hence, with no differences detected between the properties of the ganglia of the strains, the cause of resistance probably lies elsewhere.

Housefly heads from susceptible and resistant strains were compared for cholinesterase inhibition by " diazoxon " and no difference found. Inhibition in both strains was partially reversible by diluting the solution of inhibited enzyme, and experiments in the Warburg suggested that the body extract partially protected the head cholinesterase from inhibition. The protection was greater when the body extract and " diazoxon " were incubated together in strong than in weak solution. (Lord and Molloy.)

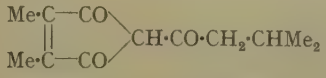
Pyrethrins and related compounds

Calythrone. Earlier work showed that the lower boiling of the two " enols " obtained from pyrethrolone by the action of methanolic sodium methoxide was a substituted cyclopentenedione, and a general route to cyclopentenediones by oxidation of the corresponding ketols was developed (*Rep. Rothamst. exp. Sta.* for 1960, p. 144). Interest was thus stimulated in calythrone, an alkali-soluble compound isolated from *Calythrix tetragona* Lab., for which the structure 4, 5-dimethyl-2-isovalerylcyclopentene-1, 3-dione (I) was proposed, but attempts to confirm it by synthesis failed. Calythrone was interesting, because the suggested structure is related to that of valone, 2-iso-valerylindane-1, 3-dione, which has had some commercial use as an insecticide. The synthesis was therefore attempted. It was found impossible to acylate a preformed dimethylcyclopentenedione in the 2-position, either using a sodium derivative of the cyclopentenedione or with a condensing agent such as boron trifluoride or aluminium chloride and an acid chloride or anhydride.

By using the highly active condensing agent sodium hydride, dimethyl dimethylmaleate was condensed with isobutyl methyl ketone to give calythrone and an acyclic ester (II), so formulated from its properties and because it could not be cyclised to calythrone by further treatment with sodium hydride.

This synthesis confirmed the proposed structure for calythrone, because all the chemical and physical data agreed with those reported for the natural product. When applied to adult mustard beetles by topical application in a 1-μ l. drop of acetone the LD50 lay between 0·05 and 5% w/v. An earlier test with valone indicated that the LD50 for this material was approximately 0·2% w/v, so

under the conditions of test calythrone is likely to be less toxic than valone.

(I) 

(II) $MeO_2C \cdot \overset{t}{C}Me{=}CMe \cdot CO \cdot CH_2 \cdot CO \cdot CH_2 \cdot CHMe_2$. (Elliott, Jeffs and Needham.)

Chemistry and biological activity of the separate active constituents of pyrethrum flowers. The work done in collaboration with the Tropical Products Institute and the Statistics Department, on the separation and reconstitution of the four known active principles of pyrethrum flowers, and on their relative biological effectiveness to houseflies, alone and in combination with piperonyl butoxide, was prepared for publication. (Sawicki, Dr. E. M. Thain,*, Elliott, Gower and Mr. M. Snarey*.)

Effect of esterase inhibition on the insecticidal activity of pyrethrum extract. If the pyrethrins are hydrolysed by the esterases in insects their toxicity might be lessened. To test this possibility the toxicity by topical application of a 1 : 1 w/w mixture of the pyrethrins with an esterase inhibitor (diazinon) was compared with that of the two insecticides applied separately. No synergism was found, hence esterase activity probably has no effect on the insecticidal action of the pyrethrins. (Sawicki.)

Pick-up and distribution of dieldrin from residual films

The mechanism of poisoning of insects by residual films was further studied using ^{14}C-labelled dieldrin instead of the ^{36}Cl material. The ^{14}C-labelled dieldrin, kindly provided by Shell Chemicals, enabled measurements to be made of the pick-up, distribution and penetration of insecticide on individual insects. The dose acquired by individual insects could be determined very exactly, so the relation between dose and susceptibility could be determined reliably.

Adult *Tenebrio molitor* were exposed at 20° for either 30 or 45 minutes to films of ^{14}C-labelled dieldrin on glass (1·5 γ/sq. cm.), removed to separate clean glass containers at 20° for up to 11 days, and then stored at −18° until analysed for radioactivity by scintillation counting. The poison was assumed not to move at −18°. During the storage period at 20° the insects were periodically classified as " alive " (alive and slightly affected) or " dead " (moribund and dead). Radioactivity was assayed on whole single insects or on dissected parts of them. The amount of dieldrin lost from the insects to their containers was also estimated.

About half of the insects, exposed for 30 minutes, died by the 11th day, which is probably near the end-point. The amounts of dieldrin picked up by individual insects ranged from 0·04 to 0·20 γ/insect, with a mean of 0·113 γ. The amounts outside and inside the bodies of 148 insects, and lost to their containers, followed distribution curves, which were skewed towards the higher values. The mean of the amounts on and in insects still alive after the 11th

* Tropical Products Institute.

day was 0·093 γ insect, significantly less than the 0·132 γ on and in the dead insects. The mean amounts inside live and dead insects differed more (0·073 γ living insect and 0·116 γ dead insect). However, the living insects had lost more poison (0·014 γ insect) than those that had died (0·010 γ insect). The amounts outside the bodies after 11 days were about the same in each group, averaging 0·0063 γ on each live and 0·0068 γ on each dead insect. The amounts picked up and the percentages lost to the containers were negatively correlated.

In a similar experiment, with insects exposed for 45 minutes and kept for 9 days, 93% died. The amounts picked up ranged from about 0·110 γ to 0·410 γ, with a mean of about 0·230 γ/insect. The distribution curve was again skewed towards the higher values. The insects dying within 4 days contained more dieldrin (0·265 γ/insect) than those still surviving (0·200 γ/insect). The difference was larger after 9 days, when the mean amount of poison contained by the dead insects was 0·227 γ and by the survivors 0·128 γ.

TABLE 1

Mean weight of dieldrin (p.p.m. of fresh weight) found in separate parts of adult Tenebrio molitor *L. at increasing times after exposure to films*

	Mean fresh weight (mg.)	Time after removal from the film: 0 hr. All alive	6 hr. All alive	4 days: Alive	4 days: Total	4 days: Dead	9 days: Alive	9 days: Total	9 days: Dead
No. of insects used ...		*22*	*25*	23	*32*	9	2	*26*	24
Head ...	5·4	*4·6*	*2·7*	1·5	*1·7*	2·2	1·6	*2·3*	2·3
Legs ...	6·2	*17·0*	*6·9*	1·4	*1·7*	2·5	1·4	*2·7*	2·8
Abdomen ...	34·5	*0·9*	*1·9*	2·3	*2·3*	2·5	0·9	*2·0*	2·1
Thorax ...	52·7	*1·4*	*2·1*	1·9	*2·1*	2·7	1·3	*2·1*	2·1
Whole insect	98·8	*2·4*	*2·3*	2·0	*2·1*	2·6	1·2	*2·1*	2·2

Table 1 shows the amounts of dieldrin, detected at various times after treatment, in the dissected parts of the insects and in the " whole " insects (calculated as the proportional means from the separate weights of dieldrin in, and the weights of, the various parts). The insecticide was mainly picked up by the insects' legs and was distributed from there to the rest of the body, reaching an almost uniform distribution throughout the insect on the 9th day. Previous experiments (*Rep. Rothamst. exp. Sta.* for 1960, p. 142–144) showed that most of the insecticide enters the body of the insect within the first few hours, so the uniform distribution shown in Table 1 can be assumed to result from internal migration of the dieldrin rather than mechanical transference on the surface of the insect. (Rey and McIntosh.)

The effect of temperature and air movement on the rate of loss of residual films of insecticides from surfaces

Because ^{36}Cl-labelled dieldrin is being used for the initial work, contamination hazards limit the techniques that can be used to produce the residual films of insecticide. Three general methods of forming uniform reproducible deposits were studied.

Sublimation of insecticides from a warm to a cool surface. This gives minute super-cooled globules that sometimes take several days

to crystallise. The amount deposited per unit area depends on several factors, some of which are difficult to control. Considerable precautions against radioactive contamination have to be taken.

Spraying methods. Even coverage and a satisfactory deposit of needle crystals ranging from 0·1 to 5 mm. long (average 1 mm.) were obtained by spraying dieldrin in a hydroxylic type solvent ("Cellosolve") in a Potter tower at 18°–20°. The small percentage of the total sprayed material depositing on the test surface and the contamination risks make it difficult to use this method without modification, but an attempt is being made to produce a special atomising nozzle for spraying radioactive materials on to a small surface area (5 sq. cm.) in such a way that all, or nearly all, the sprayed material is deposited evenly on the test surface.

Spreading methods. When dieldrin in "Cellosolve" was applied in droplets at the centre of a glass plate, previously wetted with solvent, the results were not reproducible and the physical state of the poison after evaporation of the solvent varied. When droplets of dieldrin in "Cellosolve" were placed on dry glass and spread with the edge of a glass cover-slip, results were more reproducible and the deposits were the nearest approximation to those obtained in the Potter tower, but the needle crystals were larger (range 1–10 mm. long). This method is being used for the time being to study the loss of dieldrin from glass surfaces.

A deposit of 2 μg./sq. cm. was obtained by spreading 40 μg. of radioactive dieldrin in 10 μl. of "Cellosolve" over an area of 20 sq. cm. A central circular area of 5 sq. cm. was measured radiometrically at intervals using a masked Geiger end-window counter. With the glass plates placed very close to the counter (3 mm. from the mica end-window), a counting efficiency of better than 20% was obtained using dieldrin labelled with ^{36}Cl. Three replicates were used and the plates kept at 18°–22° shielded from draughts. Table 2 shows the rate of loss of dieldrin under these conditions. Initially volatilisation occurred at a constant rate, the loss being directly proportional to the time of exposure. After 15 days, when the deposit was down to 0·4 μg./sq. cm., the rate of loss started to decrease and the curve tended to approach the time axis asymptotically.

TABLE 2

Rate of loss of dieldrin crystals 1–10 mm. long from a glass surface kept at 18°–22° in still air

Exposure (days) ...	0	4	8	11½	15	20	25	30	35
Deposit (μg. dieldrin/cm.² remaining on plate) ...	2·0	1·6	1·2	0·8	0·4	0·15	0·075	0·05	0

(Phillips.)

Analyses

We again collaborated in work, organised by the joint BHC/DDT panel and the demeton-methyl residues panel of the Scientific Subcommittee on Poisonous Substances used in Agriculture and Food Storage, testing analytical methods for BHC and demeton-methyl. The work on BHC was completed. (Jeffs, Lord and Solly.)

The decomposition of DDT and aldrin in soil was studied as part of an experiment testing these insecticides on soil organisms done in collaboration with the Entomology Department (see p. 147). Using a modification of the method for DDT worked out by the Joint BHC DDT panel (*Analyst*, **85**, August 1960), analyses were made 3 months and 6 months after applying DDT at different rates; after 6 months the loss was 15% with 60 lb. DDT acre and 20% with 6 lb. DDT/acre.

Samples of the aldrin-treated soils are being held until a satisfactory analytical technique is developed. (Jeffs.)

Insect rearing

The following insects were reared during the year:

	Plant feeding	
Hemiptera	*Acyrthosiphon pisum* (Harris)	
	Aphis fabae Scop.	
	Brevicoryne brassicae (L.)	
	Megoura viciae Buckt.	
	Myzus persicae (Sulz.)	
	Rhopalosiphum padi (L.)	
Lepidoptera	*Diataraxia oleracea* (L.)	
	Pieris brassicae (L.)	
Coleoptera	*Phaedon cochleariae* (F.)	
	Stored product, domestic and medical	
Orthoptera	*Acheta domesticus* (L.)	
	Blaberus discoidalis (L.)	
	Blatella germanica (L.)	
	Blatta orientalis L.	
	Periplaneta americana (L.)	
Lepidoptera	*Anagasta kühniella* (Zell.)	
Coleoptera	*Oryzaephilus mercator* (Fauv.)	
	Ptinus tectus Boieldieu	
	Tenebrio molitor L.	
	Tribolium castaneum (Herbst.)	
	Tribolium confusum J. du V.	
	Trogoderma granarium Everts	
Diptera	*Aëdes aegypti* L.	
	Drosophila melanogaster Meig	3 strains including a wingless mutant
	Musca domestica L.	4 strains
Hymenoptera	*Apis mellifera* L.	3 colonies were maintained as a source of control bees for the field poisoning studies

Guppies (*Lebistes reticulatus*) were also reared.

Bioassay of insecticide residues

The Analytical Methods Committee of the Society for Analytical Chemistry, after sponsoring a survey of existing methods for bioassay of insecticide residues by Needham (*Rep. Rothamst. exp. Sta.* for 1959, p. 117) financed a study of these methods to determine their ease of working, accuracy and sensitivity.

Table 3 shows the relative sensitivity of larvae of yellow-fever mosquito (*Aëdes aegypti*), water flea (*Daphnia obtusa*), adult fruit flies (*Drosophila melanogaster*) and the fresh-water shrimp (*Gam-*

marus pulex) to solutions of pure insecticides. The actual LD50 can, of course, always be altered by changing the conditions of test.

TABLE 3

Median lethal doses (parts per million) of insecticides applied to Aëdes aegypti *larvae,* Daphnia obtusa *and* Gammarus pulex *in aqueous solution and applied to* Drosophila melanogaster *adults by exposing them over potato pulp containing the insecticide*

	A. aegypti	*D. obtusa*	*G. pulex*	*D. melanogaster*
γ-BHC	0·03	0·7	—	—
DDT	0·002 †	0·03	—	—
Demeton-methyl...	4·0	—	0·04 ‡	22
Dieldrin	0·003	0·3	0·4	0·7
Parathion... ...	0·002	0·0005 †	0·006	0·2
" Sevin " * ...	1·0	0·02 †	—	>100

* 1-Naphthyl N-methylcarbamate.
† Assessment after 2 hours; otherwise after 24 hours.
‡ Assessment after 48 hours; otherwise after 24 hours.

Attempts to use the newly hatched nauplii of the brine shrimp (*Artemia salina*) for assays failed, because too few of the eggs obtained from several sources were viable. The use of the guppy (*Lebistes reticulatus*) was also abandoned, because too few fish could be reared. Extensive inquiries failed to disclose other species that might be promising test organisms for bioassay of insecticide residues. *Drosophila melanogaster* and *Daphnia obtusa* are now the most promising test organisms. Their culture is not likely to present difficulties to analytical chemical laboratories, assay procedures can be made fairly simple and reproducible, and they are sensitive enough to the poisons tested. (Stevenson.)

Factors influencing the insecticidal activity of systemic insecticides applied as foliage sprays

(a) *Fumigant effects.* An attempt was made to assess the relative toxicity, by vapour action alone, of the following commonly used systemic insecticides: mevinphos, phorate, morphothion, menazon, " Isolan " (1-isopropyl-3-methylpyrazolyl-(5)-dimethylcarbamate), phosphamidon, " Trithion " (0, 0-diethyl S-*p*-chlorophenylthiomethyl phosphorodithioate), dimethoate, demeton-methyl, fluoroacetamide and schradan. Initial tests were made in sealed Petri dishes, using 0·05% concentrations of insecticide in diethyl ether; 0·5 c.c. of solution was applied to filter-paper in the bottom of the dish by a pipette and the solvent evaporated. Aphids (*Megoura viciae*), used as test organisms, were confined in shallow crystallising dishes by coating the sides of the dishes with polytetrafluoroethylene (" Fluon ") and placed inside the sealed Petri dish system. After a 2-hour exposure at 20° the aphids were removed to clean Petri dishes and the knockdown assessed; after a further 20 hours at 20° toxicity was finally assessed. Pronounced fumigant action in these tests was shown only by mevinphos, phorate and " Isolan ", but the possible contribution of fumigant action to the overall toxicity of systemic insecticides is being further explored.

(b) *Persistence.* The persistence of insecticidal activity of the

following systemic insecticides was compared: mevinphos, morphothion, phorate, "Isolan", dimethoate, phosphamidon, demeton-methyl, fluoroacetamide, menazon, "Trithion" and schradan. The insecticides were sprayed on to sugar beet and field beans at 0·05% in water containing 0·05% wetting agent. The plants were kept in a glasshouse at about 18°, and persistence of insecticidal activity was assessed by confining aphids on the leaf surfaces by means of light plastic cages and recording mortality. Aphids (*Myzus persicae* and *Aphis fabae*) were first put on the plants 24 hours after spraying and again at intervals until no kill was recorded. *M. persicae* were usually more resistant than *A. fabae*, though not to all the chemicals. *A. fabae* were never more resistant than *M. persicae*. Toxicity persisted for from 1 to 15 days, depending primarily on the insecticide. The order of decreasing persistence was as follows: (1) phosphamidon; (2) demeton-methyl; (3) "Trithion"; (4) morphothion; (5) dimethoate; (6) fluoracetamide; (7) menazon; (8) schradan; (9) phorate; (10) "Isolan"; (11) mevinphos.

No differences in persistence were found with the two different host plants with any of the test chemicals. (Etheridge.)

Bee poisoning in the field

Insecticides and fungicides. Forty-five samples of bees suspected of being poisoned in the field were received for post-mortem examination from Mr. P. S. Milne of the National Agricultural Advisory Service. Twenty samples were poisoned by cholinesterase-inhibiting substances, i.e., organophosphorus or carbamate insecticides. Two samples, in which no other poison could be detected, gave inconclusive evidence of the presence of a cholinesterase inhibitor. Nine samples contained dieldrin and were considered to have been poisoned by this insecticide or aldrin; two of these were further samples from an earlier case of poisoning, and indicated that damage was still occurring 2 weeks later. Three samples were considered to have been poisoned by lindane.

No insecticide was found in the ten remaining samples, so these were examined for mercury and copper fungicides. One contained 8 μg. Hg per bee. A 20% aqueous sugar syrup containing phenyl mercury acetate gave an oral LD50, equivalent to 3·9 μg. Hg per bee, so it was concluded that these bees may have been killed by an organo-mercury fungicide.

Copper was present in all samples, but only in trace amounts.

Paper chromatographic techniques were developed and used to confirm the presence of insecticides detected by bioassay and to assist in their identification.

In addition to the bees, one sample of sacking and two of honey were received for examination. The sacking was thought to have been responsible for the death of bees in a hive covered with it. Tests showed the sacking to be lethal to bees both by contact and fumigant action. The information received with the sample indicated that the sacking might have been contaminated with a seed-dressing, so attempts were made to extract the toxicant and identify it by bioassay and chromatography, but these failed because of interfering substances present. However, we found that sacking impregnated with a 1% acetone solution of chemicals

commonly used as seed dressings, lindane, dieldrin or ethyl mercury chloride, was lethal to bees by fumigation, whereas phenyl mercury acetate was not.

The honey samples were from hives where bees had been poisoned with dieldrin. The source of the dieldrin was probably a wasp bait, hence it was thought that some of the bait may have been stored with the honey. Extraction and bioassay indicated the presence of dieldrin at approximately 0·04 p.p.m. Chromatographic confirmation was not possible because of the small size of the sample and the low concentration of dieldrin.

Weedkillers. Each year bees are received suspected of being poisoned by weedkillers. Therefore, the approximate oral LD50s of four common weedkillers were estimated by feeding bees with the chemicals in sucrose solution and keeping the insects after treatment at 28° C. and approx. 75% R.H. The approximate oral LD50 dose under these conditions was between 5 and 10 μg./bee for monochloracetic acid, 300 μg./bee for 2, 4-D, less than 1 μg./bee for dinoseb (DNBP) and 1,500 μg./bee for MCPB.

A technique developed for identifying MCPA, MCPB and 2, 4-D by paper chromatography was successfully used with bees poisoned in the laboratory by a stomach-poison technique. As it is unusual to receive freshly killed bees, the insects were weathered for 10 days after poisoning, but these three weedkillers were recovered and identified at levels that would be likely had poisoning occurred in the field.

The samples received this year which showed no other cause of death were examined for MCPA, MCPB, 2, 4-D and DNOC, but none was found. The techniques outlined would not detect dinoseb or monochloracetic acid. (Needham and Solly.)

Control of the spread of potato viruses

To improve the timing of sprays used to check the spread of viruses in potato crops, detailed information is needed about when spread occurs. The time of spread was again studied by spraying with insecticide at different times during the life of the crop. Potato aphids were few, and the most counted in the crop was 194 per 100 leaves on 29 June. Numbers then declined, but rose slightly in September. The insecticide treatments controlled the aphids, but effects on virus spread will not be known until next year.

Dimethoate, applied in the soil at 4 and 5 lb./acre of active ingredient in an experiment at Efford in 1960 (*Rep. Rothamst. exp. Sta.* for 1960, pp. 117 and 148), almost prevented the spread of leaf roll; at 2 lb./acre, like fortnightly sprays of DDT, it decreased spread to one-fifth of that in the control plots. Spread of rugose mosaic was halved by the dimethoate treatment, but unaffected by DDT.

A previous experiment (*Rep. Rothamst. exp. Sta.* for 1959, pp. 127–128) showed that shoots from potato tubers harvested from plants treated with soil insecticides when infested with adult *Myzus persicae* carried fewer aphids a week after infestation than shoots from control tubers. Shoots from tubers harvested from the 1960 experiment at Efford tested similarly gave no consistent difference in aphid populations between control and treated tubers. In the 1958 experiments the shoots from treated tubers grew initially

more slowly than those from untreated tubers, but no such differences in growth occurred with tubers from the 1960 experiments. The difference in measurable residual effects was probably because dimethoate was applied at lower rates (2–5 lb./acre) in 1960 than in 1958 (10·5 lb./acre).

Another experiment at Efford this year tested the effectiveness of treating seed tubers or soil with systemic insecticides in checking virus spread. Four chemicals were used:

1. Menazon as a dispersible powder suspended in water and sprayed on to the seed tubers immediately before planting at the rate of 1·3 lb. active ingredient/acre = 0·8 lb./ton of seed.
2. Phorate applied in the drill at planting as a 10% granular formulation at 4·5 lb./acre active ingredient.
3. Dimethoate in the drill as a 6·9% granular formulation at 4·7 lb./acre active ingredient.
4. " Disyston " (diethyl *S*-[2-(ethylthio)ethyl]phosphorothiolothionate), in the drill as a 5% granular formulation at 1 lb./acre active ingredient.

The layout and procedure were similar to those of the 1960 experiment. The granular materials were applied by a specially built, light, hand-propelled machine, incorporating a Gandy Row Crop Chemical Applicator. The machine was fitted with an electric speedometer to ensure accurate application rates, and was convenient and efficient in practice.

Potato aphids were fairly numerous, reaching 950/100 leaves in the control plots on 8 June. Table 4 shows aphid counts at the different plots and includes for comparison counts on nearby potatoes sprayed with DDT and demeton-methyl.

TABLE 4

Potato aphids per 100 leaves (Haulms burned off 5 July)

	20/4	4/5	24/5	30/5	8/6	23/6
Menazon	0	0	6	5	61	25
Phorate	0	2	2	0	1	3
Dimethoate ...	0	1	13	24	115	26
" Disyston " ...	0	0	0	0	1	1
Control	5	1	70	436	950	175
Demeton-methyl ...	—	—	—	58 *	1 †	—
DDT	—	—	—	39 *	5 ‡	—

* Sprayed 24 May. † Sprayed 6 June. ‡ Sprayed 7 June.

Phorate and " Disyston " were most effective, controlling aphids throughout the life of the crop. Menazon was equally effective until 11 weeks after planting, but its efficiency then decreased, possibly because the small quantity applied remained close to each seed tuber, and therefore out of reach of many of the late-developed roots of the plants. Dimethoate, very efficient in two previous experiments, was relatively ineffective, perhaps because the weather during the 1961 experiment was much drier than during the two earlier experiments. Dimethoate slightly delayed the emergence of the plants, and menazon caused slight initial discoloration of their leaves, but no treatment decreased yield significantly.

The laboratory of the Government Chemist found the following insecticide residues in tubers harvested from each treatment: phorate, 0·15 p.p.m.; dimethoate, 0·13 p.p.m.; menazon and " Disyston ", less than 0·05 p.p.m. (Burt, Dr. L. Broadbent (Glasshouse Crops Research Institute), Heathcote.)

Seed dressings with insecticides

Glasshouse tests compared the toxicity to aphids and the persistence of the following thirteen systemic insecticides when applied in a slurry to the seed: American Cyanamid 18133 (0 : 0-diethyl-0-2-pyrazinyl phosphorothioate), demeton-S-methyl, demeton, demeton-methyl, dimethoate, " Isolan ", menazon, morphothion, phorate, phosphamidon, schradan, " Disyston " and " Trithion ". Tests were made with wheat seed and *Rhopalosiphum padi*, kale seed and *Brevicoryne brassicae* and rubbed sugar-beet seed and *Aphis fabae*. Rates of application in terms of grams of active ingredient per 100 g. of seed were 0·2 and 0·4 for wheat, 2 and 4 for kale and 0·44 and 0·88 for sugar beet. Some differences in degree of toxicity and persistence could be related to the species of seed used, but the differences were not great.

The toxicity and persistence of the chemicals differed considerably, and the degree of initial toxicity to the aphids was unrelated to the persistence of toxicity. The maximum period over which aphids were all killed was about 40 days, although populations were affected for a further 10–30 days. Dimethoate best combined high insecticidal activity with a long persistence, but demeton, phorate and " Disyston " were also good. " Isolan " was tested only on kale, and was very effective over a long period. Menazon and American Cyanamid 18133 were very persistent, and would probably have been more insecticidal at higher rates. Schradan and " Trithion " were ineffective.

The uptake by mustard and wheat of phorate applied as a slurry to the seed was studied. Removing the seed coat of mustard at intervals after treatment and then sowing the embryos showed that the insecticide does not penetrate the seed coat into the embryo before germination. The seedling obtains nearly all the insecticide from the soil through its roots, but a little is picked up by the cotyledons and hypocotyl as they force their way through the soil. When phorate is applied as a slurry to wheat seed, some insecticide passes directly from the endosperm into the seedling, but most of the insecticide is absorbed by the roots from the soil. Only insignificant amounts of insecticide are picked up by the coleoptile as it emerges through the soil. Thus, it seems that with one insecticide and technique of application, the mode of uptake may differ with different species of seed. Mode of uptake is also likely to differ with different chemicals, or with changes in the formulation or technique of applying a given chemical. (Bardner.)

An experiment with dry powder dressings containing 70% of γ-BHC on seeds of cabbage and white mustard confirmed unpublished findings by workers of Plant Protection Ltd. that small particles (13–39 μ diameter) of seed dressing protected seedlings from flea-beetle attack better than large ones (260–390 μ diameter). (Bardner.)

Work, primarily on the use of seed dressings to control wireworm, continued in collaboration with the Entomology Department. Details are given in the report of the Entomology Department. (Raw, Bardner and Potter.)

Fungicides

The control of potato blight

Potato leaves are infected by spores of *Phytophthora infestans*, the cause of "blight", only when there is free moisture on their surfaces. Infection therefore might be checked if leaf surfaces could be made sufficiently water-repellent. To study this possibility, tests were started with wax "emulsions" and a water-soluble silicone preparation, on detached leaves and on single growing plants. The results were assessed by measuring the advancing and receding contact angles of distilled water on the upper surfaces of the leaves. The angles give a measure of the water-repellency of the surface. The advancing angle determines how easily water spreads over the surface; the receding angle determines how easily water is shed by the surface. The two angles are seldom the same; the advancing is nearly always larger than the receding angle.

The wax preparations, known commercially as "emulsions", were made by emulsifying hot waxes directly in water, but at the time of use are more accurately called suspensions. The preparations used were: (*a*) 1% carnauba wax emulsified with 0·35% "Armac T" (Messrs. Armour Hess Chemicals Ltd.); (*b*) 1% carnauba wax emulsified with 0·88% "Armac T", with the addition of 1% "Stockalite", a finely divided kaolin (Messrs. English Clays, Lovering, Pochin, & Co. Ltd.) to increase the surface roughness; the effect of this is to increase the advancing contact angle; (*c*) 1% "Cardis 319", an oxidised microcrystalline wax (Messrs. Cornelius Produce Co. Ltd.), emulsified with 0·4% "Armac T"; (*d*) 0·35% "Armac T" only; (*e*) 4·3% paraffin wax emulsified with 1·3% bentonite and 1·3% ammonium linoleate (U.S. Patent 2,013,063; 1935).

Single field-growing Ulster Supreme plants were sprayed with each of these on two to four occasions from 8 August to 4 September; the plants, except those sprayed with (*b*), were almost undamaged. Leaves were sampled on six occasions after spraying. The changes in water-repellency were small but very consistent. The length of time for which the advancing contact angles on sprayed leaves differed from those on unsprayed leaves, with the mean angles during this time, were: with (*a*) 25 days, 76°; with (*c*) 8 days, 65°; with (*d*) 37 days, 69°; with (*e*) 27 days, >90°; and on unsprayed leaves, 84°. Thus, the effect of these sprays, except the paraffin wax–bentonite–ammonium linoleate suspension, was to lower the advancing contact angle of water on the leaf surfaces, i.e., to make them slightly more easily wetted than the unsprayed leaves. The effect of these treatments on blight infection was not measured, but any effects must be very small. However, wax emulsions are said to reduce transpiration by the plants, and may therefore be of value, in conjunction with copper sprays, in checking the increased transpiration and loss in yield which sometimes follows copper spraying of potatoes.

The silicone preparation used was " Dri-Sil 37 " (Messrs. Midland Silicones Ltd.). This is a stable aqueous concentrate of sodium methyl siliconate which is normally used to make masonry water-repellent. Films formed from such solutions react with the atmospheric carbon dioxide to form the corresponding silanol, which polymerises at ordinary temperatures to form a water-insoluble and highly water-repellent deposit.

The following remarks refer to 1 : 20 solutions of " Dri-Sil 37 ". The pH is high (about 11·5); but the high pH probably does not persist for long in the thin chemically changing film on a treated surface. The surface tension (about 66 dynes/cm.) is only slightly less than that of water, i.e., too high for such a solution to spread really efficiently over a potato leaf. However, the siliconate is compatible with some surface-active agents; the function of each of the two components in such mixtures seems to be unaffected by the presence of the other. The mixtures are surface active and spread efficiently over potato leaves, yet dry to water-repellent films. The surface tensions of freshly formed surfaces of siliconate solutions containing 0·01% of " Ethomeen S/25 " (Messrs. Armour Hess Chemicals Ltd.) or " Manoxol OT " (Messrs. Hardman & Holden Ltd.) were 39 and 27 dynes/cm.; the corresponding figures for the surface-active agents in water alone were 38 and 30 dynes/cm.

However, the proportion of surface-active agent need not be so low as 0·01%. When detached potato leaves were sprayed with siliconate solutions containing 0·1% of either surface-active agent and kept for 24 hours the leaves were undamaged, and the advancing contact angle on the leaves was over 90°; the corresponding angle on untreated leaves was 58° (Majestic) or 85° (Ulster Supreme).

When detached Ulster Supreme leaves were sprayed with a siliconate solution containing 0·01% " Ethomeen S/25 " and kept for 24 hours, the leaves were undamaged and the advancing and receding contact angles were, on sprayed leaves, 94° and 67°, and on unsprayed leaves, 84° and 12°. When water was applied to the sprayed leaves it did not form a film on them, but formed itself into drops which rolled off, leaving the surface dry.

The deposits left by simple siliconate mixtures are rather brittle, and the water-repellent effect did not persist for very long on field plants. Single Ulster Supreme plants in the field were sprayed with siliconate solutions, with and without 0·01% " Ethomeen S/25 ", on five occasions from 10 August to 29 August. Damage was slight, except when the weather was very hot at the time of spraying. Leaves were sampled on six occasions after spraying. The advancing contact angle on sprayed differed from that on unsprayed leaves for only 8 days after spraying; the mean angles during this time were $>90°$ and 84°. No measurements were made this year on the effect of the increased water-repellency on blight infection. (McIntosh.)

The effects of chemicals used to control seed- and soil-borne diseases in forest nurseries

Both in 1960 and 1961, soil treatment with formalin and chloropicrin usually had no effect on numbers of Sitka seedlings surviving,

but significantly increased their height. The response to formalin varied less than the response to chloropicrin.

Formalin was applied at 250 ml. of 18% formaldehyde per sq. yd. soil, by watering-can in 4–5 litres of water, depending on soil moisture. Chloropicrin was applied by soil injector to a depth of 6 inches at the rate of 16 shots/sq. yd. each of 2 ml. of approximately 100% active ingredient. Both chemicals were applied in December 1960 and January 1961 and seed was sown in late March.

This series of experiments at five sites was modified to test the effects of single and repeated doses of formalin. At Old Kennington, Sitka grew significantly better on plots treated once than on plots given repeated doses annually. Formalin greatly decreased numbers of fungi per unit of plot soil, but had comparatively little effect on numbers in rhizospheres. In both locations the different types of fungi responded very differently to treatment. Treatment decreased the incidence of species of *Cylindrocarpon*, *Fusarium* and *Mortierella* and increased the prevalence of *Penicillium canescens* Sopp, which seems to be an important coloniser of partially sterilised soils.

The effects of several chemicals and methods of application were tested at Old Kennington and Ringwood. These included presowing treatments with metham-sodium (165 g./sq. yd. in 4–5 l. of water, applied in the same way as formalin, in January), thiram (112·5 g. of 15% dust/sq. yd., broadcast, in February), quintozene (112·5 g. of 25% dust/sq. yd., broadcast, in February), and formalin (rate as above, in January); and a post-sowing drench of maneb (2·0 g. of 80% dust in 2–4 l. of water, applied 5 times at monthly intervals). At both sites all treatments except thiram increased the numbers of surviving seedlings, maneb giving consistently large increases. Formalin increased the height most, with metham–sodium next. Maneb increased height appreciably at Ringwood, but not at Old Kennington.

Work on chemical control of Sitka diseases has largely been concerned with the soil-borne organisms. Seed-treatment experiments started in 1960 were continued and indicate that seed-borne fungi may cause appreciable losses. Application of thiram, captan or organo-mercury fungicides increased numbers, but not heights, of seedlings, even with apparently clean seed. Dieldrin mixed with fungicides had no effect on seedling development. (Last and Ram Reddy.)

Work on attempts to control take-all of cereals by chemicals is described in the report of the Plant Pathology Department.

ENTOMOLOGY DEPARTMENT

C. G. Johnson

K. Mellanby left to become Director of The Nature Conservancy Field Station, St. Ives, Hunts, and T. Lewis was appointed in October; C. J. Banks returned from a secondment to the Institute of Nuclear Science, Central Treaty Organisation, Iran. Mr. G. K. A. Buahin of the Division of Agriculture, Ghana, and Mr. R. MacGregor-Loaeza of The National Institute of Agricultural Research, Mexico, joined the Department as visiting members. Dr. E. Dimelow of Mount Allison University, New Brunswick, came in the summer to study the annelid and mollusc food of hedgehogs, and Mr. S. Agwu (Eastern Nigeria) also visited the Department.

K. Mellanby, who was appointed to the Inter-University Council for Higher Education Overseas, visited Hong Kong in March at the invitation of the Hong Kong Government, to advise on the establishment of a second University there; he also lectured in the Republic of the Philippines. C. G. Johnson visited Ceylon in October to advise on aphid research, at the invitation of the Ceylon Tobacco Company.

A. J. Cockbain and D. S. Madge were awarded the Ph.D. degree of London University.

Soil Fauna

There are three main lines of study: the biology of earthworms and soil arthropods in relation to soil fertility; the effects of insecticides and other chemicals on pests and on beneficial (or at least innocuous) soil animals; and the biology of pests which live in the soil.

The breakdown of vegetable matter in the soil by soil animals

Part at least of the contribution of earthworms to soil fertility is their burying of plant material, so beginning the process of its incorporation into the soil. This activity occurs at different rates according to the weather. Recent work on orchards, where leaf burial has been studied for some years (*Rep. Rothamst. exp. Sta.* for 1959, 1960), showed that from December to March rainfall had little effect on the rate *Lumbricus terrestris* bury leaves, presumably because the litter never dried out and soil moisture was never a limiting factor at this time; but burial rate was positively correlated to soil temperature.

Once the leaves are buried, worms also help to break them down. Disks of leaf placed at three levels in the litter layer of oak and beech woods showed that fragmentation was almost entirely by earthworms, and only about 2% of disks showed signs of skeletonisation by Collembola and other small arthropods. Fragmentation, which occurred almost exclusively in the lowest litter layer, was at its peak in February and March, decreased in April and occurred only sporadically till August; later it increased again to a peak in the

spring. Like leaf burial, fragmentation was related to weather and depended on the moisture content of the litter, beginning after heavy rain and stopping in dry weather. Oak and beech woods had similar populations of worms, an approximate fresh weight of 1,000 lb. earthworms/acre, with *Lumbricus terrestris* more common than *L. rubellus*.

Leaf breakdown is not always done by earthworms, however; in arable land worms are assisted by small arthropods. So far the importance of various species of soil arthropods in leaf breakdown has been obscure, but a new method enables these activities to be analysed. Leaf disks were encased in nylon bags of various meshes and buried in the soil. The mesh regulates the entry of different-sized animals reaching the leaf disks. This method, coupled with studies on changes in the composition of the soil fauna after treatment with different insecticides and nematicides, indicated that Collembola and Dipterous larvae are important in the initial breakdown of leaf disks (worms being excluded by some bags) and that numbers of Collembola in plots treated with different insecticides were correlated with the amount of feeding as shown by the erosion of the disks.

This work was supplemented by studying changes in the total soil carbon levels and the proportion of undecomposed plant material extracted by flotation on concentrated $ZnSO_4$ solution. The degree of fragmentation of disks is also being followed by estimating the changes in hydrolysable carbohydrate. These processes of leaf breakdown are correlated with changes in the metabolic activity of soil organisms and attempts are being made to assess this by measuring changes in the CO_2 of the atmosphere of blocks of soil. (Edwards, Raw, Heath and Lofty.)

The effect of chemical control on pests and on other arthropods and worms in the soil

The extensive use of chemicals to control insects and other pests often leads to toxic substances accumulating in the soil, and it is important to know how such treatments affect predators of pests and soil organisms concerned with litter breakdown and soil fertility.

Thus, in addition to studying how cultivation and manuring affect earthworm populations, attention was also given to the effects of spraying with copper fungicides. One orchard with a long history of such spraying had accumulated 1,500–2,000 p.p.m. of Cu in the surface litter. Laboratory studies were therefore made to see the effects of feeding a mat of partially decomposed litter with this high copper content to earthworms. *Lumbricus terrestris* seemed unharmed and pulled the mat into its burrows, but several other species died after feeding on it. (Raw and Lofty.)

Preliminary work showed that single applications of widely used soil insecticides can greatly affect both the numbers and the proportions of various species of arthropods in arable land; in general, population decreases, but the various groups of animals are not all equally affected. DDT decreased the numbers of Mesostigmatic mites, but simultaneously *increased* the numbers of Collembola, presumably because it removed the mites which normally prey on the Collembola. (Edwards.)

The ecological effects of applying DDT and aldrin are being studied on Highfield, with plots kept completely free from plants. Some Collembola prey on nematodes, so effects on nematodes are being studied by C. Doncaster (Nematology Department); the rate at which the insecticides disappear is being measured by K. Jeffs (Insecticides Department). At the end of the first 6 months all the DDT treatments (at 6, 20 and 60 lb. a.i./acre) again decreased the numbers of predacious mites, and increased Collembola, which were five times as numerous as in the untreated plots. DDT at 6 lb. a.i./acre increased the Orobatid mites. Aldrin did not affect the numbers of predacious mites, but Symphyla, Pauropoda, Protura, Diptera, Coleoptera, Hymenoptera, Lepidoptera and Hemiptera were all diminished greatly by all treatments except the lowest rate of DDT. (Edwards, Raw and Lofty.)

The effect on the soil fauna of accumulations of aldrin from regular applications, at rates commonly used in agriculture, is being studied at Levington Research Station by courtesy of Messrs. Fisons Ltd. Aldrin is applied annually, to crops in a rotation of sugar beet, barley, potatoes and winter wheat, from 1 to 2 lb. a.i./acre according to the crop; 6-monthly samples of soil will show faunal changes, and crop yields will be taken. Already, after 1 year, the total arthropod population in the treated fields was only 57% of that in the controls; Acarina, Collembola and other arthropods were respectively 44%, 62% and 68% of their levels on the untreated plots. (Edwards, Raw and Lofty.)

Ecological effects of soil fumigants

Soil fumigants are commonly used to control nematodes and pathogenic fungi, but their effects on other soil-inhabiting organisms have been almost ignored. A programme to study the short- and long-term effects of some nematicides on soil arthropod populations was begun in greenhouse beds with a high arthropod micro-fauna, using "D.D. Mixture" (50% 1 : 2-dichloropropane, 50% 1 : 3-dichloropropene). Changes in the horizontal and vertical distribution of the populations caused by fumigation, and the rate and form of recolonisation of treated soil, are being studied. (Buahin and Edwards.)

The arthropod fauna of different soil habitats

Because different species of arthropods are concerned with litter breakdown in different habitats, the composition of the fauna is being studied in heathland, woodland moss, woodland litter, sphagnum moss and in six plots on Park Grass, Rothamsted, that carry different plant species. In a 2-year census of the first four habitats over a quarter of a million arthropods recovered consisted of Arachnida (75%), Collembola (23%) and other arthropods (2%). 90% of the Arachnida were orobatid mites and 7% and 3% Parasitiform and Trombidiform mites. All these proportions were approximately the same for all four habitats.

Over 90% of the mites and Collembola were restricted to the litter and humus layers or to a soil depth of 2 cm. There was no obvious vertical migration during the year, probably because of the

relatively even temperatures and the unfavourable underlying layers, which were either sand or clay.

The life histories of some orobatid mites were also studied. There may be one generation annually, as in *Platynothrus peltifer* (Koch.), *Achipteria nitens* (Nic.) and *Fuscozetes fuscipes* (Koch.), two, as in *Tectocepheus velatus* (Mich.) and *Nanhermannia nana* (Nic.), or possibly one generation in every 2 years in *Belba geniculosa* Oudms. (Madge).

Taxonomic work on the Symphyla continued, and specimens from India, Jamaica, Hawaii, Europe and the United Kingdom were studied. (Edwards.)

The biology of soil insect pests

Pests studied include lepidoptera, wireworms and slugs; and experiments on their behaviour, growth, development, fecundity and mortality in relation to environment, especially temperature, help in analysing the causes of outbreaks.

Laboratory and insectary studies of British cutworms aim to show how temperature affects the speed at which eggs and larvae develop and how different food plants affect growth of larvae of the Large Yellow Underwing (*Tryphaena pronuba* (L.)). The reactions of the larvae to light are particularly interesting. Like many other newly emerged insects, first instar larvae show strong positive phototaxis, a reaction which is reversed as the larvae enter later instars, when there is also a nocturnal feeding rhythm related to this, for larvae emerge from the soil only in the evening. The way these reactions are affected by temperature and humidity changes are also being studied. (Madge.)

Experiments continue on the effect of temperature on the speed of development of wireworms (Raw) and on the temperatures needed to complete the life histories of the Ghost Swift Moth (*Hepialus humuli* L.). Larvae of the Ghost Swift pupated when kept at 10°, 15° and out of doors; but those kept at 20° continued to grow and to moult. This indicates that the life cycle is usually completed in one season, but that sometimes it may be extended into the next. Adults of this insect and a related species, *H. lupulinus* (L.) (The Garden Swift Moth), were also caught in light traps as part of a general biological study of these insects. Fewer were caught and over a longer period than in 1960. Eventually larval and adult biology will, no doubt, be correlated. (Edwards.)

Slug biology

The movements of slugs, particularly the rate and manner in which they invade crops, are little understood, and an experiment is being made with three pest species (*Arion hortensis*, *Agrolimax reticulatus* and *Milax budapestensis*). A small garden plot with wide grass margins, on which the three species are prevalent, was cultivated and weeded all the spring and summer, so decreasing the slug population except on the grass margins, where it remained steady. Iron plates were driven 15 inches into the ground all round one-half of the plot on the inside of the grass margin, and the whole plot was planted with winter wheat. From the amount of slug damage and

from counting slugs on the two halves, it is hoped to assess how populations of the three species increase by reproduction and by invasion from the margins. The effects of soil tilth on oviposition and movement of slugs are also being studied. (Stephenson.)

Soil pest control

Studies continue in collaboration with the Insecticides Department on the chemical control of wireworms by means of seed-dressings: γ-BHC, dieldrin, aldrin at standard and increased amounts were applied to winter wheat seed as liquid and spray (aldrin) and as dust combine-drilled with the seed (γ-BHC). Treatments were applied in spring 1960 soon after Claycroft was ploughed out of old grass. Counts in autumn 1960 showed that, except for liquid aldrin, all treatments had decreased the wireworm population. Effects on yield were not measured, because the unavoidably late sowing produced a poor crop. Residual effects from the insecticides applied in the spring of 1960 were detected on a crop of Cappelle wheat drilled in autumn 1960: when harvested in 1961, yields from all plots treated in spring 1960 were higher than from the untreated plots. Tests for further residual effects are being made.

Another experiment was begun to compare the effect on the wireworm population of the seed-dressings used with spring- and autumn-sown crops. Cappelle wheat treated as in the 1960 (spring) experiment was sown in November 1960; and Jufy wheat, treated with a high dose of γ-BHC and standard dieldrin, was sown in April 1961. Estimates on the autumn-sowing in the spring (1961) showed that all treatments had greatly decreased wireworm damage, although at harvest only high-dosage γ-BHC plots gave significantly higher yield than controls; however, the γ-BHC combine-drilled with the seed came close to this. There was little evidence of wireworm damage to the spring-sown wheat, but at harvest standard dieldrin-dressed seed gave significantly higher yields than the untreated. (Raw and Lofty, with Potter and Bardner, Insecticides Department.)

After last year's work on the repellent properties to slugs of dimethyl phthalate, dibutyl phthalate and of salicyl aldehyde (*Rep. Rothamst. exp. Sta.* for 1960, p. 159), further tests are being made with aldehydes of higher molecular weight, applied as seed-dressings to winter wheat.

Insect Dispersal and Migration

Various aspects of the migration process, and of other forms of dispersal, with many insect species have been systematically studied for some years. With aphids, and particularly with *Aphis fabae*, the migration process was studied in its three parts, namely, the rhythms of emergence and of the post-teneral flight of the alatae; vertical and horizontal dispersal or the migration flight itself: the deposition of aerial populations and the infestation of new habitats, including crops. Various studies under these headings now proceed with many insects besides aphids.

Flight thresholds and flight periodicity

One of the most important factors affecting flight is its temperature threshold. Thresholds for both take-off and for sustained flight were obtained for *A. fabae* in the laboratory and field (*Rep. Rothamst. exp. Sta.* for 1959, p. 291, and 1960, p. 162). The main difficulty in estimating the flight threshold of a species from trap catches in the field has been to dissociate the variation in catch caused by behaviour, to which the threshold applies, from variation caused by changes in population level, to which it does not. For example, a zero catch could reflect a small population rather than a sub-threshold temperature.

A new method has now been developed for analysing trap catches so as to reveal flight threshold temperatures, and was applied to catches of queen wasps and species of aphids, beetles and moths; it remains to check these results against flight thresholds found experimentally in the laboratory. (Taylor.)

The degree of dispersal arising from the initial departure of insects on their migratory flights from breeding places depends largely on the time of day when most fly. When this is in the daytime the convection and turbulence of the atmosphere ensure maximum dispersal; daytime flight can be regarded as an evolved adaptation to this end, as with aphids. Crepuscular or nocturnal flight can be an adaptation to limit dispersal to times of minimum air movement. The flight periodicity of insects is, therefore, an essential part of migration studies, and is bound up with the process of crop infestation. Records of periodicity of the diffusion of insects through the upper air have already been obtained for many insect species at Cardington, and the factors controlling periodicity at the source of supply were analysed for *A. fabae* (*Rep. Rothamst. exp. Sta.* for 1956, p. 153). Other records have now been collected at eight different sites at ground level to establish typical patterns of flight periodicity for many insect groups throughout the year, and a comparative table of flight periodicities of many taxonomic groups is being made. This will illustrate factors controlling periodic flight and the likely methods of dispersal of many insects. It will be complementary to the more generalised dispersal periodicities in the upper air. A striking feature of the new results is the parallel division of at least three families of Diptera—Chironomidae, Mycetophylidae and Cecidomyidae—into two clearly defined groups of darkly pigmented daytime flyers and pale night-flying species. The Diptera is the only Order so far found which shows this evolved flexibility of periodicity. (Lewis and Taylor.)

Crop infestation by aphids

Aphids are borne on the wind to crops, but they probably alight on them only when wind-eddies carry them into shelter inside the crop. An experiment in 1961 was designed to test the mechanism of such alighting by arranging bean plants in certain patterns, with variation in spacing and plant size, in the field; the resulting patterns of infestation were studied in relation to wind speed and direction. In 1962 other experiments will supplement this work and should help in understanding the control exercised by the aphids

when alighting in different circumstances, and on the subsequent movement of newly arrived migrants in the crop. (Taylor.)

Field experiments were also made to see whether the incidence of pea-leaf-roll virus in different bean varieties was associated with different degrees of infestation by the aphids, *A. fabae* and *A. pisum*. The degree of primary aphid infestation of seven bean varieties (Granta, Strubes, Tick 30b, Albyn Tick, Spring Tick, Minor and Metz Frey) did not differ greatly and was not related to the ultimate incidence of the virus. (Taylor with Gibbs, Plant Pathology Department.)

The physiology of aphid flight

Variation in flight thresholds and flight durations of *A. fabae* in relation to changes in temperature, humidity and fuel consumption, and the effects of prolonged flights on subsequent behaviour, reproduction and survival have already been closely studied (*Rep. Rothamst. exp. Sta.* for 1959, p. 139 and, 1960, p. 162). Similar work is now in progress with *Myzus persicae*. *M. persicae* can fly for up to 16 hours non-stop in a fixed position; the factors affecting flight prolongation are being analysed, together with their relation to settling behaviour and subsequent parturition and larval production. (Cockbain.)

Insect immigration records

Numbers of immigrant Lepidoptera were well below the average in 1961, except for six species. Very few migrants were seen in the first half of the year; the Painted Lady (*Vanessa cardui* L.), the Red Admiral (*Vanessa atalanta* L.) and the Clouded Yellow (*Colias crocea* F.) were scarce during the whole year. Increase in abundance of some species, especially the Silver Y (*Plusia gamma* L.), the Delicate (*Leucania vitellina* Hübn.), the White-point (*Leucania albipuncta* Schiff.), the Vestal (*Rhodometra sacraria* L.) and the Gem (*Nycterosea obstipata* Fab.) in September were presumably because of late immigration.

The outstanding immigrant of the year, the Crimson Speckled (*Utetheisa pulchella* L.), has been recorded at least twenty-nine times to date (12 January 1962) a number exceeded only once, in 1892 (forty-nine). (French.)

The Biology of Aphids

Aphis fabae is a member of the " black aphid complex ", which contains several closely related species and biological forms within species. Taxonomic characters and their variability have long been controversial issues and, even in one species, have not been fully studied biometrically. Bean aphids and others in this complex are now being reared on various hosts and at different temperatures, and it has been possible to change the proportions of the mouth parts of *A. fabae* by temperature treatments, so that they resemble those which distinguish *fabae* from the Tropeolum aphid (*Rep. Rothamst. exp. Sta.* for 1959, p. 138). This is not only significant taxonomically but is also related to the ability of aphids to feed successfully

and so to colonise different hosts. (Taylor, with Dr. V. Eastop of the British Museum (Natural History.))

Aphid feeding and excretion

The growth and reproduction of aphids depends on the efficiency with which they use the host plant as a source of food; an understanding of resistance and susceptibility of plants to aphid attack and the way in which viruses are acquired and transmitted also demands a knowledge of how food is ingested. The measurement of feeding rates and the factors which affect it are therefore significant in the general context of aphid biology as studied in this department. Such measurements can be made directly, using radioisotopes or (such is the speed at which food is taken and passed through the gut) by measuring the rates at which honeydew is secreted. These excretion rates are now being studied in *A. fabae*. The number of honeydew drops excreted by aphids from birth to death are counted by catching them on moving bands of indicator papers. Their volumes are measured from time to time, from the diameter of droplets collected in mineral oil. Thus the rate of imbibing food can be related to the growth and reproduction of the insects, and their efficiency in using the host can be assessed. (Banks.)

Aggregation in Insect Populations

A power law relating the variance to the mean, which gives an index measuring the degree of aggregation in different-sized populations, was described last year. Ideal material to test these degrees of aggregation (using this method) and the way in which they may be related to development, reproduction, behaviour and environmental factors is the long series of records of the numbers of wheat-midge larvae in wheat blossoms, collected for 35 years by the late H. F. Barnes. This material is now being analysed. An essential first stage in this, and indeed in the analysis of many samples, is the use of the appropriate transformation; power-law transformation tables for this purpose are being prepared. (Taylor, with Healy, Statistics Department.)

The Efficiency of Insect Traps

One of the major efforts of this department has been to rationalise and to standardise insect trapping. Before the suction trap, catches were rarely related to a spatial dimension of the environment; numbers caught from time to time were related only to themselves as a series. Suction traps relate the catch to a volume of air sampled and thus assess aerial density, which is an absolute measure related to a size dimension of the environment. There were three stages in this development: the empirical design of traps, the standardisation of the amount of air sampled in different wind speeds and the measurement of trap efficiency.

The most efficient trap is not the one which catches the most insects, but the trap which allows fewest insects to escape from the sample of air as it is taken in; it is therefore the trap with the smallest error in making the density estimate. Hitherto, with

suction traps, and indeed with nets and sticky traps too, corrections have been applied to assess the amount of air sampled; and density estimates have often been made from the standardised catch on the assumption that the efficiency, at least for small insects (e.g. aphids), was close to 100%. This assumption was accepted and thought to involve a serious error only with large insects. Efficiency has now been measured for all types of suction trap developed in this department; it depends on insect size, trap size and wind speed. Tables are now being published from which the catch can be converted, with a known error, to density/unit volume of air, for any of the suction traps, catching insects of almost any size, in all wind speeds likely to be relevant. (Taylor.)

From new data and from Gregory's work on spore traps (*Rep. Rothamst. exp Sta.* for 1951), the aerodynamic efficiency of sticky traps for insects was also assessed; from Johnson's work on sticky traps and tow-nets, and from additional results with a whirligig trap, the efficiencies of all these traps was also calculated and tables prepared for converting their catches to aerial densities. Most of the efficiency of the sticky traps for small insects is explained in terms of the deposition of inert particles on cylindrical surfaces. (Taylor.)

Thus the programme on design, operation and standardisation of insect traps, especially suction traps, begun in 1946, has now been completed and the work brought to an end.

The Transmission of Viruses in Relation to the Behaviour and Physiology of Alate Aphids

A winged aphid will not remain on a host plant unless it has made a flight, and the duration of the flight partly determines how long the aphid will remain and feed on a plant. The profound changes in alate settling responses associated with differences in flight history may, therefore, affect the spread of viruses by winged aphids in the field, and winged aphids may differ from unwinged ones in the acquisition and transmission of viruses. Tethered winged *A. fabae* and *M. persicae*, previously bred, or merely fed, on both infected and uninfected plants, were flown for various lengths of time, and their subsequent powers of acquiring and transmitting the non-persistent pea and beet mosaic viruses were studied. The loss of infectivity during flights of different duration was also assessed.

A flight of only $\frac{1}{4}$–$\frac{1}{2}$ hour is enough to induce either of the two aphid species to settle on a new host long enough to acquire either of these viruses, and longer flights rarely increased the number of aphids in a batch that became infective. However, *A. fabae* that had flown transmitted both viruses more readily than unflown ones which had been starved to induce them to feed (starvation periods shorter than 24 hours in the dark did not induce settling in the light). Starved *M. persicae* were more prone than starved *A. fabae* to probe before flight.

No *A. fabae* and only few *M. persicae* reared on infected plants transmitted virus to healthy plants when transferred to them before or after they had flown. After flying, a brief feeding period on an infected plant made both species infective. Made infective in this

way, some aphids still transmitted the viruses to healthy plants after they had had tethered flights of 4 hours at 25°, but the number that transmitted decreased with increasing duration of flight. This suggests that even these non-persistent viruses may occasionally be transmitted after natural flights of many miles. However, this is much more likely with sugar-beet yellows virus, with which ability to transmit was unaffected by a 4-hour flight; the ability was lost before the wing muscles autolysed (3–6 days) by aphids fed on healthy plants between daily flights of 15 minutes each. (Cockbain, with Gibbs and Heathcote, Plant Pathology Department.)

The Ecology of the Cabbage Whitefly (*Aleyrodes brassicae* Walk.)

To find the relations between the whitefly populations developing on crops and the amount of movement, individually and collectively, within and beyond the crops by flight, adults were counted on the leaves of a kale crop, suction traps were operated above the crop, and the rate clean plants sited at different distances away from the crop became infested was measured. Temperature is a principal factor controlling the rate individuals mature, the rate the populations increases and their flight. The effects of temperature will be studied at different stages of the life history.

The shortest mean incubation period of eggs was 5·9 days at 27°, and the longest mean period was 18·2 days at 14·5°. Only 4% of eggs hatched at 10°, and they took at least 34 days, and this temperature is regarded as the development-hatching threshold. Between 14·5° and 28° about 90% hatched, but above 28° mortality increased.

Although there were winged whitefly on the crop between the end of November 1960 and April 1961, no new ones emerged, and low temperatures prevented flight. Aerial populations developed from April and reached a peak on the crop when the first generation of adults emerged at the end of May. In June, when the crop was old, leaves became dry on the plants and the number flying decreased. During this time there was a gradient of insects away from the crop, and clean plants put at distances up to about 50 feet away became colonised by flying adults. Trapping over a new crop began again in August, and populations were in the air until November, when temperatures below 10° again became limiting.

Hourly catches with the suction trap showed that there is always a peak of flight during the daytime, and sometimes also a considerable peak at night. To fly by day and night is very unusual with insects. Light is not a limiting factor in the flight of whitefly, as it is with aphids, and failure to fly by night is determined by low temperature. In summer and early autumn flight peaks are determined partly by rhythms of emergence and partly by temperature-controlled variations in the teneral period before flight. As with aphids, most adults emerge in the early morning and have a teneral period of 3–10 hours at normal daytime temperatures. The time of flight is governed by temperature and also by the condition of the leaves. All newly emerged adults left the leaves on which they were born in a matter of hours, and before they laid eggs. Migration, however, and the daily (and nightly) peaks, do not involve long

flights, and most of the insects fly only from the old lower leaves on which they emerged to new, young leaves on the same crop, and often even on the same plant, where they settle and lay eggs.

In the late autumn, however, very large mass flights occur, which take clouds of insects away from the crop. These flights, which appear to be far larger than the number of newly emerged adults, are probably composed partly of adults prevented from laying a full complement of eggs by low temperatures which are not too low to stop flight. (Imam El Khidir.)

Ecology of the Frit Fly, (*Oscinella frit*, L.)

To check frit fly populations on oats, insecticide is applied to young plants in the tiller stage early in spring, so as to kill larvae hatched from eggs laid by adults then invading the crop. Early sowing also allows plants to grow beyond their most susceptible stage before this attack begins, but a second generation of adults from grassland and oat tillers in early July lays eggs in the developing oat panicles, and larvae from these eggs attack the grain.

Control by insecticides might be improved if more was known about the source of adults ovipositing in oat panicles, and this is being sought by studying the factors influencing sizes of populations on grassland, movement to oats, the build-up there and the return to grasses.

Trapping of frit fly over spring oats, begun in 1960, continued at the same site in 1961; peak catches of adults of the three generations during 1961 were on 13 May (11 June 1960) 5 July (4 July 1960) and 19 August (23 August 1960). The peaks for the second and third generations were at the same times in both years, but the important spring generation was a month earlier in 1961, and reasons for this were sought.

Far fewer frit fly adults attacked oat tillers in 1961 than in 1960, a difference attributable partly to a higher mortality of the over-wintering generation on oats. Half of the larvae and three-quarters of the pupae of frit-infested winter oats died. However, the populations on grassland near the oats did not differ greatly in the two years, and the smaller attack on oat tillers in 1961 was partly attributable to cold weather depressing migration from the grasses.

Hourly suction-trap catches show that the threshold for take-off is about 16°, but the evening flight stops while temperatures are above 16° because light becomes the limiting factor. (Calnaido, French and Bull.)

Oats become infested in spring by frit flies migrating from grassland, but whether from near or far is uncertain. Also, adults which emerge from oat panicles in August return to grasses, but again flight habits and distances flown are unknown. Neither is it clear whether adults from oat tillers infest the panicles on the same crop or whether they come from elsewhere. Analysis of catches at Cardington up to 1,000 feet in the air go some way to show how frit fly migrate. In August the flies of the panicle generation reach a peak of aerial density in the morning, when turbulence and convection are greatest, and, swept up high into the sky, 50% of the aerial population occurs above 1,300 feet. The daily dispersal finishes by late

afternoon. Clearly, frit fly, like aphids and many other insects too, are adapted to migrate at high altitudes, and this allows the population to disperse over an immense area when acquiring new habitats. It now has to be discovered whether the generation emerging from tillers in the oats behaves in the same way. (Johnson and Taylor, with Dr. T. R. E. Southwood of the Imperial College of Science and Technology.)

Spiders

The effect of food and temperature on Zygiella x-notata (Clerck).

Spiders were fed with different numbers of adult *Drosophila melanogaster* at temperatures from 15° to 30°. Partial starvation and excessive food increased the number of instars, but partial starvation lengthened the instars. The number of instars also increased with rising temperature. *Z. x-notata* is well adapted to withstand starvation, and adult males have been reared on as little as one *Drosophila* a week, when they may be only $\frac{1}{12}$ the weight of a well-fed one.

Gall Midges

Populations of Swede Midge (*Contarinia nasturtii*), assessed by daily emergence rates and bi-weekly counts on plants, were much smaller in 1961 than in 1960. There were only two, late, generations in 1960 compared with three and a partial fourth in 1961. The late attacks produced only slight symptoms, and "swollen petiole" was very rare. Several National Agricultural Advisory Service Centres recorded slight attacks, but the infestation was large at Newcastle. (Edwards with H. Bardner, née Twigg, Ministry of Agriculture, Plant Pathology Laboratory.)

BEE DEPARTMENT

C. G. Butler

In January C. G. Butler lectured in the U.S.A. at the invitation of the American Institute of Biological Sciences. In September J. Simpson attended the International Union for the Study of Social Insects Congress in Italy, L. Bailey took part in a Conference in Madrid organised by the International Office of Epizootiology, and J. B. Free and C. G. Butler attended a Conference of Bee Research Workers, followed by the International Beekeeping Congress, in Madrid.

Behaviour and Physiology

Swarming

A colony of bees deprived of its hive and combs behaves like a swarm, first clustering on the nearest convenient support, then suddenly dispersing into the air either to cluster again near by or to fly in a body across country to a new nest site. When several colonies were simultaneously deprived, and the first cluster started to disperse the others could be induced to do so by holding them close to the first one. Bees from the first cluster alighted on the other clusters and performed the " schwirrlauf " movements described by Lindauer (*Z. vergl. Physiol.* **37**, 263–324, 1955). A colony deprived of its hive and combs only ½ hour earlier was " triggered off " in this way. Bees on combs did not respond, however, though they became somewhat excited. The nature of the stimulus is not certain. Recordings of the sounds made by the bees of a dispersing cluster had no effect when played to a combless cluster. As all the bees of the colonies that could fly took part in the dispersals, the behaviour induced in these experiments is analogous to the " absconding " of whole colonies rather than to a reproductive swarming in which only part of a colony goes off in a swarm. However, absconding bees, once they have left their hive, behave like a reproductive swarm; the behaviour of a swarm seems intrinsic to bees at all times and not to depend on any physiological changes resulting from swarming out of a hive or any lengthy preparation for swarming or supersedure.

Further evidence that individual bees can be induced to swarm without lengthy preparation was provided by an experiment in which the bees of a colony that was swarming were diverted through the hive of a colony that was not even preparing to swarm. The swarm, when collected, contained as high a proportion of the bees of the second colony as of the first. (Simpson.)

Queen pheromones

When colonies whose hives and combs had been removed had their queens taken away the clusters of workers tended gradually to disperse and join colonies in nearby hives. Such dispersal of a

cluster could be prevented, however, when its queen was caged and suspended among the workers, even when the cage had double wire-gauze walls preventing the workers from touching their queen. When the queen was removed from such a cage the workers persistently gathered on its wire-gauze walls, but never on its wooden parts, though these contained the entrance where any contamination from the queen would occur when she was put into and removed from the cage. Once, when a cluster dispersed, leaving its caged queen behind, the bees flew about 50 m. in a straight line, then circled for a time before eventually returning to their caged queen. These observations show that the workers of a colony can detect the presence or absence of their queen without touching her, and suggest that they can even do so when flying as a swarm towards a new site. It is difficult to understand how chemical perception can operate in a moving swarm, unless the queen flies at its head. (Simpson.)

Observations by Gary (*Science*, **133**, 1479–1480, 1961) indicate that most of the queen scent that attracts worker bees is produced in the mandibular glands, but olfactometer experiments showed that it is not the 9-oxodecenoic acid ("queen substance") produced in these glands. A scent that queens produce does, like 9-oxodecenoic acid, partly inhibit queen rearing by worker honeybees; it acts synergistically with 9-oxodecenoic acid to inhibit queen rearing completely. Removing a queen's mandibular glands seems not to decrease the inhibitory scent, which, like 9-oxodecenoic acid, is present on all parts of her body. When different parts of living queens, whose mandibular glands had been removed several weeks previously, were tested the inhibitory scent was always found on all parts, so it is probably produced in glands widely distributed over her body. The evidence suggests, therefore, that a queen's inhibitory scent is probably distinct from her attractive scent, but this cannot be demonstrated until one or other of these scents has been obtained pure. Whereas virgin queens produce very little 9-oxodecenoic acid until they are about 10 days old, even newly emerged virgin queens produce some inhibitory scent, but old, mated, laying queens produce more. The scent alone presumably explains the fact that young virgin queens can partially inhibit queen rearing by their colonies. (Butler.)

Queen rearing

In commercial queen rearing female larvae are transferred from worker cell cups and given to queenless colonies to rear as queens. Much labour could be saved if the transfer could be avoided by getting eggs laid in the cups. When a queenright colony is given empty artificial cups of the usual pattern, however, it invariably mutilates them, even though its queen may be laying in natural queen-cell cups. When natural cups (removed from colonies) and artificial cups, mounted in a frame used for queen rearing, were presented simultaneously to a queenright colony, all the artificial cups but none of the natural ones were mutilated. Plaster-of-paris moulding showed that the internal shapes of the two differed; in particular, the mouth of a natural cup is constricted and only about the width of a worker cell, whereas the mouth of the type of arti-

ficial cup used was its widest part. Colonies given artificial cups made with the internal dimensions of natural ones did not mutilate them; a few eggs were laid in those in the colony whose queen had been laying in natural cups, and queens were reared from these eggs. However, no method has yet been found for getting a queen to lay eggs in many cups, whether artificial or natural.

When twelve empty natural queen-cell cups were left overnight in a queenless colony five had eggs in them next morning. These eggs were removed, but 24 hours later another egg was found in a cup. The worker bees must, therefore, either have transferred the eggs from worker or drone cells or laid them themselves. This result was not repeated when the experiment was repeated with another colony. (Simpson.)

Pollination and Field Behaviour

Some tree-fruit varieties need to be pollinated from other varieties. A suggestion from previous work (see *Rep. Rothamsted exp. Sta.* for 1960), that main variety trees next to pollinisers are better pollinated than those farther away, was tested. In an apple orchard where four rows of a variety needing cross-pollination were planted together the row nearest the pollinisers had about twice the fruit set of the other rows. A plum orchard with only two rows of a polliniser variety bisecting it showed an even greater contrast; about 7% of the flowers of the main variety trees adjacent to the polliniser rows set fruit, but four or more rows away the average set was less than 1%. In the row beside the polliniser row there was even a difference in set between the sides of the trees facing and away from the pollinisers. Similarly, where cut branches of the polliniser variety were placed in the main variety trees, the set was greatest closest to these branches. This suggests that the methods currently recommended for arranging polliniser varieties among main variety trees will not always give maximum pollination.

Bees foraging on a crop of field beans were selected at random and observed for as long as possible, and the behaviour of distinctively marked individuals was recorded from day to day. Three types of visit were distinguished: to the extra-floral nectaries, for nectar; to holes bitten by bumblebees at the bases of the flowers, for nectar; to the mouths of the flowers, for nectar and pollen. Most individuals persisted in one or other type of visit, and instead of changing their type of visit tended to desert the crop for part of the day when their type of visit became unprofitable. Because bees visit the extra-floral nectaries of field beans before the flowers open and tend to persist in this behaviour, it is probably best to delay taking colonies to the crop until the flowers themselves are open.

Previous work (see *Rep. Rothamsted exp. Sta.* for 1960) showed that feeding syrup to colonies increases their pollen-collecting activities, so it might be worthwhile to feed colonies used to pollinate beans, as all pollen-gatherers are efficient pollinators. (Free.)

Bee Diseases

European Foul Brood disease

Strains of *Streptococcus pluton* isolated from diseased larvae from North and South America, Britain and Switzerland were all of the same serological type and quite unrelated to any strain of *Streptococcus faecalis* ("*Streptococcus apis*") isolated from diseased larvae from the same places. (Bailey, with Gibbs, Plant Pathology Department.)

Cultures of *S. pluton*, various strains of *S. faecalis* and of *Bacillus alvei*, all derived from diseased larvae, were tested for pathogenicity in field experiments by inoculating them into the food surrounding individually identified larvae. Only *S. pluton* and one strain of *S. faecalis* caused nurse bees to eject the larvae (very few larvae were found diseased or dead, even when inoculated with natural disease material: most were ejected from the colony within a few days). Laboratory and field tests showed that those larvae that successfully reached the propupal stage after they had been infected with *S. pluton* were lighter in weight than usual and voided many live bacteria in their faeces, whereas those infected with *S. faecalis* were of normal weight and voided few or no live bacteria. Although some strains of *S. faecalis* may be pathogenic, therefore, they seem unable to survive long in larval intestines and seem unlikely causes of endemic disease. (Bailey and Lee.)

S. pluton, isolated and propagated on media containing the extract of one larva/10 ml. of medium, was significantly more effective or virulent than bacteria isolated and propagated on plain medium. Controlled field tests showed that dry smears of the contents of midguts of diseased larvae became non-infective after fumigation with acetic acid in the way recommended for combs contaminated with *Nosema apis*. (Bailey.)

Nosema apis

Some spores of *Nosema apis* in dried faecal deposits kept at 20° and 50% R.H. were alive after 12 months, but most had died. All were dead after the same time in honey.

In endemically infected colonies the percentage of infected drones was about one-quarter that of infected worker bees. That drones have less infection is not surprising if infection comes mainly from faecal contamination on combs and not from stored food, because drones do not clean combs. The percentage of drones infected was nevertheless high (14% in one colony), so they may be infected by receiving contaminated food from workers engaged in both comb-cleaning and brood-feeding.

Because many beekeepers claim recently that sodium sulphapyridine controls infection, tests were made by infecting caged bees with spores in syrup containing 0·5 g. sodium sulphapyridine per 100 ml. (The drug was previously found non-toxic to bees at this concentration, which was about the dose recommended.) The bees were incubated at 30° for 10 days and supplied with the drugged syrup *ad lib.* After this time the number of spores that developed in the ventriculi of drugged bees was the same as in control bees similarly infected and then fed with ordinary syrup. Sulphapyri-

dine is ineffective, therefore, at preventing either spore germination or the multiplication of the parasite; the results confirm those of controlled field experiments made elsewhere years ago. (Bailey.)

Paralysis

Many adult bees became paralysed about 8 days after they had been sprayed with aqueous extracts of naturally paralysed bees and incubated at 30°. This confirmed previous workers. Bees sprayed with extracts of healthy bees were unaffected. Aqueous extracts of naturally or artificially paralysed bees shaken with carbon tetrachloride and centrifuged at 8,000 g. for 10 minutes were bacteria-free but still infective. Bees injected through an abdominal intersegmental membrane with such extracts made from paralysed bees became paralysed after about 4 days, but they also did so when injected with similar, although more concentrated, extracts of most bees from several apparently healthy colonies. Bees injected with water similarly treated with carbon tetrachloride remained healthy.

Infective extracts contain isometric particles resembling those of many viruses. They are 28 mμ in diameter and have the characteristic ultra-violet absorption spectrum of a nucleoprotein. The particles occurred not only in naturally and artificially paralysed bees but also in some bees that seemed healthy. Artificially infected bees contained at least 100 times as many particles as apparently healthy individuals.

A whole healthy colony, sprayed on different occasions with extracts of paralysed bees, produced crops of paralysed individuals at about 8-day intervals after each spraying, whereas naturally affected colonies produce paralysed bees more continuously. These and other observations suggest that hereditary differences between bees determine whether the paralysis virus increases to lethal numbers. Artificially infected bees, which are usually resistant to the spread of their own virus, presumably became diseased because they received an overwhelming dose of virus by unusual routes of infection. (Bailey and Lee, with Gibbs, Plant Pathology Department.)

STATISTICS DEPARTMENT

F. YATES

The following members of the Department left during the year: Beryl Turner on marriage, D. J. Knight to take a post with De Havillands Aircraft and J. R. Davis to take a teaching post in mathematics with the Universities Mission to Central Africa. Appointments were: G. J. S. Ross from Cambridge University and M. L. Hill from Ferguson Radio Corporation.

Yates acted as consultant to the Seminar on Sample Surveys of Road Transport organised in Geneva by the Inland Transport Committee of the United Nations Economic Commission for Europe. Yates, Healy and Patterson attended the 33rd Session of the International Statistical Institute held in Paris, at which Yates and Healy gave a paper on the application of electronic computers to research statistics (12.14). Healy attended the General Assembly of the International Union of Biological Sciences in Amsterdam on behalf of the Biometric Society, of which he is Secretary. Leech attended the Fourth International Congress on Animal Reproduction held at The Hague and gave a paper on the construction of an index of herd fertility (12.9). B. M. Church spent three months in Ethiopia on behalf of the United Nations Economic Commission for Africa to report on problems and techniques for livestock surveys in Africa, to draw up a programme for a livestock survey in Southern Ethiopia and to organise the initial stages of the fieldwork for this survey. Earlier, at the invitation of the Foreign Office, he attended a Central Treaty Organisation seminar on sampling methods in Lahore. Vernon spent a month in Nigeria with the Federal Department of Agricultural Research, Ibadan, advising on agricultural experiments.

F. B. Leech was awarded the D.Sc. degree of the University of Belfast. S. F. Buck was awarded the Ph.D. degree of the University of London, for his work, while an Agricultural Research Council Scholar, on the relation between rainfall, temperature and actual transpiration and the yields of wheat, sugar beet and potatoes (12.3).

The additional building for the Department was completed and occupied in January 1962. This has relieved the very serious overcrowding, which became particularly acute in 1961 because of associated alterations in Rivers Lodge and the Hut.

Four temporary workers spent varying periods in the department during the year, three from overseas.

THE 401 COMPUTER

The 401 computer was very intensively used throughout the year. The regular system of overtime, introduced at the beginning of 1961, enabled more hours to be worked with less strain on the scientific staff (86% over laboratory hours, compared with 56% in 1960). This would have been impossible without the willing co-operation of the machine operators, who volunteered for late duty, and the engin-

eers, who undertook late working in addition to " on call " duty. Fearne, who supervised the arrangements, is especially to be commended for the smooth working of the system.

The machine itself continues to give reliable service. The trouble mentioned in the 1960 Rothamsted Report, due to interference from the motor driving the new drum, continued into 1961, but was cured, with the assistance of the manufacturers, by replacing the drum motor by the old motor used to drive the disk. Since then no further trouble has been experienced.

The new drum store has more tracks than the original disk store. We have now designed, built and installed a unit which enables eight of these additional tracks to be used, thus making available 31 tracks (3,968 words) instead of 23 tracks (2,944 words) (Rees). This increase in storage capacity enables us to tackle certain problems previously impossible. In particular, the construction of the General Experiments Programme referred to below would have been impracticable without this increase.

TABLE 1

Record of machine operation for 1957–61

	1957	1958	1959	1960 *	1961
Total hours worked	2,622	2,869	2,993	2,757	3,688
Productive work, hours ...	1,305	1,676	2,211	1,853	2,666
Percentage overtime ...	32·6	45·1	50·8	55·9	86·5
Percentage of time for					
Productive work	49·8	58·4	73·9	67·2	72·3
Programme development, etc.	22·6	16·8	10·3	17·4	11·8
Idle time	4·4	1·7	0·7	0·4	0·3
Maintenance, etc.	23·3	23·2	15·1	15·1	15·6
Total	100·1	100·1	100·0	100·1	100·0

* 46 weeks. The machine was out of commission for 6 weeks in 1960 because of the failure of the magnetic disc.

Table 1 records machine operation for the years 1957–61 in the same form as in previous reports, except that time required for maintenance, both scheduled and unscheduled, and time wasted by machine faults, are grouped together; the subdivision between these items is very similar to that of earlier years. The productive computing time increased from 1,853 hours in 1960 to 2,666 hours in 1961 (an increase of 44%). This is attributable in part to the increase in hours worked, in part to less time being required for programme development and in part to the loss of 6 weeks in 1960 from the magnetic disk failure.

Table 2 shows the number of experiments analysed in 1961 and in earlier years and also the number of variates (which is a rough measure of the amount of computer work). Fewer experiments were analysed than in 1960, when there were over 2,000 simple experiments from Bihar and Pakistan, but 36% more variates. Excluding Bihar and Pakistan, the number of variates analysed per experiment was 5·5 in 1960 and 5·3 in 1961.

The time spent on different classes of work was recorded. Slightly under 30% of the productive computing time was spent on

TABLE 2

Numbers of replicated experiments analysed in the department

	Number of experiments:—			
	By hand	On computer	Total	Number of variates on computer
1934	115	—	115	—
1951	437	—	437	—
1955	384	419	803	834
1956	181	683	864	1,701
1957	98	1,253	1,351	5,041
1958	182	1,664	1,846	6,260
1959	67	2,649	2,716	11,102
1960	85	3,687	3,772	11,147
1961	89	2,862	2,951	15,184

the analysis of experiments and an almost equal amount on the analysis of surveys. Almost all the survey analysis was done by the General Survey Programme developed in 1960.

GIFT OF A 402 COMPUTER

Late in 1961 we were generously offered a gift of a 402 computer by Elliott Brothers. This machine, which is about 5 years old, has been in use in the Elliott Computing Service Bureau. The 402 is essentially a production version of the 401, with almost identical electronics but with a different order code.

The machine has now been installed and commissioned. We propose to use the 401 card-reader for the 402, and this is now being fitted; as the machines are so similar, we do not anticipate any difficulty in this. The machine has been placed in the same room as the 401, so that the same operator can tend both machines. It is intended to use the 402 almost wholly for survey analysis, thereby freeing time on the 401 for other work. The General Survey Programme written for the 401 has already been transcribed for the 402 (Simpson), but has still to be tested. It may also be possible to link the magnetic tape unit to the 402. This will further increase its power for survey analysis.

THE ORION COMPUTER

Final decisions were reached on the peripheral equipment for the Orion. Three Ampex magnetic tape units were ordered. Input will be by five- and seven-hole paper tape and punched cards; output will be wholly by seven-hole paper tape. After further consideration it was decided not to install punched-card output or line-printer output at present.

The manufacturers are regrettably behind schedule, and it is not now expected that the machine will be delivered before the spring of 1963. Because of the delay in delivery, and because also final particulars on autocodes, etc., are still awaited, we have not yet organised any formal courses on the Orion for statisticians at other Agricultural Research Institutes, but it is hoped to do this during 1962.

Programming Developments

The General Survey Programme completed in 1960 was used extensively throughout 1961 and proved an extremely powerful tool for processing large bodies of data. The machine time devoted to the analysis of surveys and similar types of analysis has increased by 67% in 1961. Although some similar programmes have been written for other, and larger, machines, ours is, I believe, still the most powerful programme in existence for the types of analysis required in survey research work.

Preliminary work on the construction of a similar General Survey Programme for the Orion has started (Simpson and Gower). Gower prepared a paper on the methods we have adopted for handling multi-way tables on the computer, and made suggestions for autocode instructions covering these operations for inclusion in the Mercury Autocode (12.7). Simpson has extended the General Survey Programme to deal with sampling on successive occasions, but this extension is not yet fully tested.

As mentioned in last year's report, the development of the General Survey Programme suggested that a similar approach might solve the general problem of the analysis of replicated experiments of varied design on computers (see also (12.13) and (12.14)). Other commitments delayed this work early in the year, but it was resumed in the autumn. A General Experiments Programme is now almost complete, and large parts of it have been tested (Yates, Simpson and Gower).

The basic principles of this programme are similar to those of the General Survey Programme. The particular analysis required is specified by a series of instructions which control the whole sequence, often very complex, of operations which require to be performed. It would, of course, be intolerable to have to write and punch a new set of instructions for the analysis of each experiment, and it is therefore intended to provide standard sets of instructions for the commoner designs. Provisions have been made in the programme which permit groups of designs of a given type (e.g., $3 \times 3 \times 3$ designs in blocks of 9 with two or more replicates) to be covered by a single set of instructions, and which allow minor variations in the analysis.

The General Experiments Programme requires a considerably more elaborate repertoire of instructions than is needed for survey analysis, and its implementation taxes the capacity of the 401 (including the newly enlarged store) to its limits. It has not been possible to incorporate many refinements which would make it more convenient to use. The programme will also undoubtedly be slow compared with our existing ones for the analysis of standard designs, so we do not intend that it should replace such programmes where these exist. It will, however, fill many gaps in our present set of programmes, notably in the directions of covariance analysis, complex factorial designs, incomplete blocks and long-term experiments. It will also serve as a prototype which will give us the necessary experience to construct a more powerful and sophisticated programme for the Orion.

These two general programmes typify our present ideas on the way in which our much larger future computer will be used. We

confidently expect that outside users, both full-time statisticians and others, will take advantage of our computing facilities much more than has been feasible so far. For this to happen, we shall have to insist on these users handling as much as possible of their problems themselves. They cannot be asked to learn the Orion machine code, and only fairly regular users will become proficient in the general autocodes that will be available. As we shall not have enough staff to write or adapt programmes for the wide variety of problems that will arise, we propose to write what will amount to several very specialised autocodes simple enough for their use to be learnt quickly.

It is interesting that the general programmes for surveys and experiments, both of which in large part consist of operations on multi-way tables, have large sections in common, and it now appears probable that one programme will suffice for both the analysis of experiments and for the analysis of the results of surveys, once the basic tables have been constructed from the original survey data. This has clearly many advantages, both to the writers of the programmes and to the users.

Bonsall completed a programme that enables programmes written in the Orion symbolic input language to be tested on the 401. Not all the Orion facilities are included, and the size of the simulated programme is limited, but this simulation programme should be a considerable asset when we start writing Orion programmes during 1962. If it is found that the programme makes excessive demands on machine time it may be re-written for the 402. A small amount of work has been done on the inverse problem of running 401 programmes on the Orion (Bonsall and Rees). An Orion programme which would enable the Orion to accept 401 programmes, and run them at reasonable speed, would certainly ease the formidable problems of the change-over period after the Orion is installed.

Gower wrote a programme for covariance analysis of data organised in a hierarchical or nested classification with up to eight levels. In connection with this, he devised an algorithm for calculating the coefficients needed to estimate components of variance in unbalanced data, and an auxiliary programme embodying this has been written (Martin). These programmes were applied to a large collection of data relating to the inheritance of milking characteristics in Friesian cattle (with Dr. J. S. F. Barker, Milk Marketing Board).

Experimental Design and Analysis

As in previous years, the Department analysed the results of many experiments for the National Agricultural Advisory Service and for other research stations and institutes (Dunwoody, E. P. Simpson and Holgate). Requests for the design and analysis of livestock experiments, mainly from the National Agricultural Advisory Service, increased (Frater). A report was produced on Beef Carcase Assessment, based on the data from the Beef Progeny and Performance Tests at Rosemaund and High Mowthorpe Experimental Husbandry Farms (Boyd and Frater). A paper on the residual effects of phosphate fertilisers in experiments on the

Experimental Husbandry Farms was completed (Patterson and Dr. Rice Williams (12.10)).

Theoretical work on long-term experiments continued, and a general method of analysis for experiments comparing rotations of different length is being developed (Patterson). Healy and Gower prepared a paper on aliasing in partially confounded experiments (12.8).

The errors of some 500 cereal experiments done by the National Institute for Agricultural Botany between 1956 and 1960 were examined. All the experiments used long, narrow plots and were harvested by combine. The most important conclusion is that the need for small blocks in cereal experiments is as great now as it was before combine-harvesting and long, narrow plots were introduced. An empirical rule is that the variance per plot is roughly proportional to $n^{\frac{1}{2}}$, where n is the number of plots per block. (Patterson, Ross and Mr. D. Harrington of the Agricultural Institute, Dublin.)

At the request of the Soil Fertility Committee of the National Agricultural Advisory Service Soil Chemists' Conference, reports were prepared (Lessells) on the use of gypsum on land unaffected by sea-water (12.6), on an investigation into methods of measuring stability of soil structure and on the effect of nitrogen on cereal yield (two reports). The results of case-studies on the effects of drainage on restored opencast coal sites were reported (Lessells). A paper on weight loss and sprouting in bulk-stored maincrop potatoes was completed (Dr. A. R. Wilson, Mr. P. T. G. Twiss and Lessells (12.12)).

Surveys

Surveys of fertiliser practice were done in 1961 in eighteen districts in England and Wales and five districts in Scotland; these are being analysed. Arrangements were made for a much larger survey in England and Wales in 1962. A paper is being prepared on the use of fertilisers on grassland, based on surveys done in England and Wales in the period 1957–60 (Boyd, Church and Hills). A report on a survey of fertiliser practice on fruit-growing farms in Kent was completed (Hills).

A survey done by the National Agricultural Advisory Service Crop Husbandry Officers and their staffs on the use of herbicides in four English arable-farming districts was reported (Church).

We have been concerned with five surveys for the Ministry of Agriculture's Animal Health Division. The field and laboratory records of the *Brucellosis* survey began to arrive towards the end of the year. This survey should be ready for analysis in the spring of 1962. A survey of mastitis on all farms within 10 miles of Reading was analysed (Vessey and Leech). Some further work is required before this can be written up. The Ministry also surveyed during October and November the incidence of turkey reactors to the haemagglutination inhibition test for Newcastle Disease virus. The results were reported to the Ministry (Leech). The survey of sheep losses in England and Wales during 1959/60 was analysed (Vessey). Plans were prepared for a survey of calf husbandry and losses during 1962/3 (Leech).

A large survey of dairy farms was analysed for the Milk Marketing Board (Vessey). The Board's Production Division is preparing the results for publication.

We advised on the planning or analysis of surveys of oestrus in cows (in Scotland), calf husbandry (Northern Ireland), cattle fertility (Devon and Somerset) and cattle disease (France).

Commonwealth and Overseas Work

Work continued on a large collection of data relating to control of capsids on cocoa from the West African Cocoa Research Institute, Ghana. Preliminary conclusions were communicated to the Institute and to the chemical firms engaged in capsid control research (12.2), and a paper is being prepared in collaboration with C. G. Johnson (Entomology Department) and Mr. G. Burge, formerly of the Department of Agriculture, Ghana. This work showed that there was a need for research into the conduct of experiments on cocoa. Various points relating particularly to capsid control were followed up on the Institute data, but these proved inadequate for studies on yield. With the assistance of the Institute, C. A. Thorold (Woburn) and Dr. S. C. Pearce (East Malling Research Station), complete yield records for a 6,000-tree farm extending over 15 years were assembled on punched cards. Various preliminary investigations of these figures were made, and their study is continuing in collaboration with Dr. Pearce (Vernon and Morris).

Vernon also continued his work with Mr. J. L. Gregory (Federal Agricultural Research Organisation, Nigeria) on yam beetles and collaborated with H. Greene in the design of a long-term rotation experiment to be laid down at Ibadan, Nigeria. In connection with these and other projects, he visited Nigeria during December.

A computer programme was written for Miss N. Tanburn (Department of Agriculture, Ghana) to assist with the forecasting of cocoa yields during the next decade. This involved studying the results of varying assumptions concerning rates of planting and of senescence since 1900 (Healy).

Dr. T. Eden completed a report on the analysis of the long-term experiment on coconuts for the Coconut Research Institute, Ceylon. Church visited Ethiopia for the second time on behalf of the Food and Agriculture Organisation of the United Nations to advise on agricultural surveys. Four rotation experiments from Larissa, Greece, were analysed (Gower and Ross). Bonsall is analysing a large collection of data from dairy cattle in Israel; this involves fitting parameters to the results from each animal to describe its lactation yields and subsequent analysis of the fitted values. (These last two pieces of work came to us *via* the Food and Agriculture Organisation of the United Nations.)

Other Work

Several studies with a genetical background were made, some of which have already been mentioned. Bonsall is analysing the results of ram progeny tests for the Department of Agriculture, University College of North Wales, to study the differences between

twins and singles in growth and conformation. He also collaborated with Mr. J. A. Nelder (National Vegetable Research Station) and members of the Genetics Department, University of Birmingham, in applying improved statistical techniques to estimate genetical parameters in experiments on *Drosophila* and tomatoes (12.5). Ross worked with Dr. E. C. R. Reeve of the Department of Animal Genetics, Edinburgh University, on a model for the inheritance of mu-particles in *Paramecium Aurelia*.

The statistical technique known as discriminant analysis, introduced in the 1930s, has been little used in practice because it requires much computation. In essence, it provides a means of studying the relationships between groups of individuals when several measurements have been made on each. We recently applied this technique to data from many different sources. During 1961, for example, it was used on botanical measurements from clover varieties for Miss V. Lofthouse, National Institute of Agricultural Botany (Gower), and on psychological results from groups of maladjusted children (Simpson). This last investigation was made in connection with the National Survey of the Health and Development of Children, and is part of a continuing collaboration with Dr. J. W. B. Douglas, Director of the Survey; other studies dealt with relationships between social class, family size, puberty and growth, and with the influence of home and school conditions on performance in intelligence tests. Intelligence test results from children tested at 8 and 11 years of age were also analysed for the National Foundation for Educational Research, and a large survey of methods of teaching arithmetic by the same organisation is at present being analysed (Simpson).

Other investigations include:

1. Capture–recapture studies on bats for the Earl of Cranbrook, Chairman of The Mammal Society of the British Isles (Yates and Simpson).
2. Analysis of nitrification studies by Mr. H. Barkworth, National Agricultural Advisory Service (Gower).
3. Analysis of sets of non-orthogonal data on pig growth for the National Institute for Research in Dairying and the Agricultural Research Council Statistics Unit, Cambridge (Rees).
4. Problems involving continuous recording of data, etc., for the Glasshouse Crops Research Institute (Rees and J. R. Davis).
5. Monte Carlo studies of theoretical models for competing species, with Dr. P. H. Leslie, Bureau of Animal Population, Oxford (Gower and Martin).
6. Classification problems, using methods devised by Dr. P. H. A. Sneath; several bodies of data were analysed, for the Low Temperature Research Station, the National Institute for Research in Dairying, the Commonwealth Bureau of Mycology and the London University Institute of Psychiatry (Gower).
7. Assessment of physical maturity in children from X-ray ratings of bones in the wrist and hand, for Dr. J. M. Tanner, London University Institute of Child Health (Healy).

8. Analysis of extensive data on age at menarche in Bantu girls, for the South African Institute for Medical Research (Healy (12.4)).

9. Tabulations and regressions for the Institute of Criminology, Cambridge (Rees and Hills).

10. Advice to the Ministry of Transport (at the request of the Treasury Organisation and Methods Division) on the use of computers for the analysis of origin and destination surveys of road traffic, for the planning of motorways. It is intended to make a pilot analysis on the 401, using the General Survey Programme, but data are still awaited. Full-scale analysis will require a larger machine (Yates, Rees and Healy).

Smaller problems were tackled for many individuals and organisations; these include the Imperial Cancer Research Fund, the Royal Veterinary College, the Animal Breeding Research Organisation, the Agricultural Research Council Pest Infestation Laboratory, the National Institute for Agricultural Engineering, the British Sugar Corporation, the Glasshouse Crops Research Institute, St. Albans College of Further Education and the Medical Research Council Social Medicine Research Unit. This is in addition to the regular statistical consulting service provided to other Rothamsted departments.

FIELD EXPERIMENTS SECTION

G. V. Dyke

The field experiments at Rothamsted and Woburn are controlled by the Field Plots Committee: F. Yates (Chairman), G. V. Dyke (Secretary), F. C. Bawden, G. W. Cooke, H. V. Garner, P. H. Gregory, J. R. Moffatt, C. A. Thorold, R. G. Warren and D. J. Watson.

G. V. Dyke was seconded for six months to Hunting Technical Services Ltd. to start experiments on land recently reclaimed from salinity and waterlogging in the Indus Valley, West Pakistan. J. McEwen joined the section.

In 1961 the farm staff laid out and harvested 3,115 full-scale plots on the two farms. Table 1 shows how they were divided according to crops and type of experiment.

TABLE 1

Number of full-scale plots harvested 1961

	Grain	Roots	Hay	Grazing	Total
Classical experiments:					
Rothamsted ...	227	—	126	—	353
Woburn	50	—	—	—	50
Long-period rotation experiments:					
Rothamsted ...	613	407	184	96	1,300
Woburn	136	326	40	12	514
Short-period experiments:					
Rothamsted ...	535	127	—	—	662
Woburn	76	136	24	—	236
Total ...	1,637	996	374	108	3,115

There were another 148 full-scale plots for which yields were not required, and 78 that were laid out and harvested by other staff. There were 897 microplots, bringing the total to 4,238.

Broadbalk

The land was ploughed in October 1960, but the unusually wet autumn and winter delayed drilling until 18 January 1961. The usual wheat variety, Squarehead's Master, was sown. There had been very little frost to mellow the seedbed, but the land was caught in reasonably good order, though the tilth was rather fine. The seed went in fairly well, and to roughen the seedbed it was covered by spring-tine harrows, which exposed some seed. Early growth was very slow and uneven, and in May many of the plots, including the dunged strips, looked yellow and backward. At this stage the prospects were bad and there was some doubt whether the plants would come into ear. Later there was a remarkable recovery, the crop thickened out and, though straggled before harvest, it was not lodged. The section immediately after fallow looked quite well, and in fact yielded over a ton of grain per acre on the average of all

treatments, a result only 5% below the mean of a recent 20-year period.

Broadbalk has been sown in spring on two previous occasions, in 1845, the second year of the experiment, and in 1853, the second year after the present system of manuring was adopted. In both years winter varieties were sown. Some of these yields and those recently obtained from the only other sowings made in the New Year are given below.

Year	Variety	Sown	Grain (cwt./acre) No manure	Dung 14 tons
1845	Old Red Lammas	March	12·9	17·6
1853	Red Rostock	March	3·2	10·0
1959	Squarehead's Master	5 January	—	18·8 *
1961	Squarehead's Master	18 January	11·4	17·0 *
1844–55	Mean of 10 autumn-sown crops		9·6	17·3
1950–60	Mean of 10 autumn-sown crops		10·4	21·8 †

* Plot 2B, section Ia, continuous wheat.
† Plot 2B 4th crop after fallow till 1954 then section Ia.

The March sowing in 1853 was a failure, but the other three late-sown crops were only slightly inferior in grain yield to autumn-sown wheat of about the same period. Apart from these exceptional seasons, three-quarters of the Broadbalk crops have been sown in the 3 weeks between 16 October and 8 November.

Broadbalk was very weedy in 1961, for the plant was thin and the bare places soon filled up with weed. Section V near the drain was especially bad, but even the plots bare fallowed in 1960 were far from clean.

Section Ia carrying the 10th crop of continuous wheat was sprayed with MCPA/TBA, and broad-leaved weeds were well controlled, though some appeared later in the season. Slender foxtail (*Alopecurus myosuroides*) was very prevalent. This weed had been kept in check in recent years by sowing the wheat rather late, usually about 1st or 2nd week in November, after the grass had germinated and the seedlings had been destroyed by cultivation. In 1961, however, *Alopecurus* was more plentiful than for many years, not only in the continuous wheat but also on the remainder of the field, including the first crop after fallow. The abnormally wet autumn and winter may have delayed germination till the spring. Experiments on the dormancy of *Alopecurus* seeds will be started in the Botany Department.

Hoosfield

The combined effect of the liming programme (*Rep. Rothamst. exp. Sta.* for 1954, p. 148) and a long and sustained attack on weeds, has been greatly to improve the appearance of this field and increase its demonstration value. Wild oats (*Avena fatua*), annual weeds, coltsfoot (*Tussilago farfara*) and couch (*Agropyron repens*) have all been much decreased, as have the irregularities on some of the formerly acid plots. The crop in 1961, although late-sown, yielded well. The plots with complete fertiliser gave 24·4 cwt. grain/acre, about 20% above their long-period means. Farmyard manure,

with a yield of 26·4 cwt., was also better than usual, but not to the same degree.

Barnfield

All the standard manures and fertilisers were applied in spring, and the field was bare fallowed for a second season in preparation for a new scheme of diversified cropping, in which mangolds will be one of the crops, thus maintaining a connection with the old experiment. Lawes and Gilbert's classical " mineral " treatments will still be laid along their strips, but the individual plots will be subdivided to test levels of nitrogenous fertiliser.

Exhaustion Land

The poor appearance of the plots that had received no phosphate in former years is often very striking in the early stages, but in 1960, and again this year, it was difficult to pick them out in spring. When the crop came into ear, however, plots having dung or phosphatic residues looked slightly thicker than the rest, and were obviously more forward. The land was very clean, except for some couch (*Agropyron repens*) that had survived two years' treatment with dalapon.

The Rothamsted Ley–Arable Rotation Experiment

by D. A. Boyd, G. W. Cooke, G. V. Dyke, J. R. Moffatt and R. G. Warren

Description of experiment

There have long been differences of opinion on the value of ley farming, especially in the Midland and Eastern Counties of England. To decide whether the additional costs implicit in a policy of " taking the plough round the farm " are justified by increased production per acre, we must be able to compare the productivity of land solely under arable crops and permanent grass with that of similar land devoted to a system of alternate leys and arable. The Rothamsted ley–arable experiment was designed for this purpose. In making the comparison, the production from the grassland and arable land of these two farming systems can be treated separately, and our report is mainly devoted to the yields of arable crops in different rotations, which are simpler to compare. They are perhaps the more meaningful, because very few combinations of types of sward, methods of use and management can be tested in a single experiment, and even these few may be somewhat artificial, because it is difficult to simulate normal practice when grazing small plots.

The experiment, which began in 1949, is in two parts; one is on Highfield, which was in very old permanent grass and had accommodated a grazing experiment in the period 1937–48; the other part, on Fosters field, had been arable for many years. Cropping is the six-course rotation shown in Table 1, the first three courses of which consist of grazed or conserved ley, lucerne or arable crops, followed by three " test " crops, wheat, potatoes and barley, which are common to all four rotations. In addition, there are permanent grass plots sown down at the beginning of the experiment, and, on

Highfield, plots of the original old grass sward. Apart from this, the two fields have identical cropping systems. The grazed leys and the permanent grass plots are grazed by sheep, except that a silage cut is taken in May in alternate years.*

TABLE 1

Cropping in the Ley–Arable Experiment

	Year 1	2	3	4	5	6
	Treatment crops			Test crops		
(1) Grazed ley						
(2) Conserved ley				Wheat, potatoes, barley		
(3) Lucerne hay						
(4) Seeds hay, potatoes, † oats *						
(5) Permanent Grass (Original Sward) ‡						
(6) Permanent Grass (Reseeded 1949–51)						

* From 1955 onwards, formerly barley.
† Replaced by sugar beet 1961 onwards.
‡ On Highfield only.

There are twelve blocks on each field, of which four were begun in 1948–49, four in 1949–50 and four in 1950–51. Two of the four blocks began with the first year of the leys, and the other two carried the first test crop. Thus, all six courses of the rotations are present in duplicate on each field every year. Each block contains one plot of the permanent grass sown down when the experiment began, and, in Highfield, one plot of the original grass sward.

Each whole plot measures 166 feet × 23 feet or about $\frac{1}{11}$ acre. Until 1961, when a uniform rate of N was applied, plots of the grazed and conserved leys and the arable rotation were subdivided transversely into two sub-plots to test two rates of N applied to the treatment crops. The permanent grass plots were similarly subdivided for two rates of N. The rates were:

	(cwt. N/acre) Low rate	High rate
(1) Grazed Ley	0·15	0·30
(2) Conserved Ley (*per cut*) * ...	0·15	0·30
(3) Lucerne Hay	—	—
(4) Arable: Seeds Hay	0·3	0·6
(4) Arable: Potatoes	0·5	1·0
(4) Arable: Oats	0·2	0·4
(5) & (6) Permanent Grass	0·15	0·30

* Usually about 5 cuts/year.

The sub-plots of the grazed and conserved ley rotations and the arable rotation were further subdivided lengthways, to provide a test of two rates of N on all test crops, and two rates of FYM (12 tons *v.* none) to the test crop of potatoes. For the grazed and conserved leys the interaction (treatment N × test N × FYM) was confounded with pairs of blocks. Test crops following lucerne had the same tests for N and FYM on quarter-plots as the other rotations. Until 1961 there was also a test of FYM to the other crop of potatoes in the arable rotation, arranged so that on each field there was only a

* The original plan was to take a periodical hay crop from the permanent and reseeded grass plots, but this was abandoned in 1957.

half-replicate of the four factors tested. The higher levels of N for each of the three test crops were assigned to the same sub-plots, so that the responses to N applied to barley, for example, will be augmented by any residual N from the wheat and potatoes.

In the previous grazing experiment on Highfield in 1937–48, the production was measured both by sheep and cattle weights and by sample cuts. The estimated yields of starch equivalent from the sample cuts proved to be in reasonable agreement with those estimated from the grazing animals. These two methods of assessment were therefore adopted initially for the Ley–Arable experiment, but with considerable modification. As the grazing sub-plots are only $\frac{1}{22}$ acre, compared with 5 acres in the previous experiment, grazing has had to be by sheep, only on the "on-and-off" principle, teams of six to eight sheep grazing each sub-plot for 2 days. Sample cuts are taken immediately before the sheep are turned on to the plots. Weighing the sheep was discontinued in 1958, and yield is now estimated solely from the sample cuts.

Originally, the basic PK manuring was 0·4 cwt. P_2O_5 and 0·4 cwt. K_2O/acre annually for all rotations and for permanent grass. These amounts of K were too small and led to serious K deficiency on the conserved ley and lucerne rotations. This was recognised in 1954, and supplementary dressings were applied from 1955 onwards to these two leys and to the permanent grass and, in 1957 and 1958, to the test crop of wheat following the conserved ley and lucerne. Because of the differential withdrawal of K from the plots, the yields of the test crops are of little interest until the last few years. Comparisons, substantially unaffected by this factor, can be made between the three ley rotations for the wheat crop from 1957 onwards, for potatoes from 1958 onwards and for barley from 1959 onwards. Supplementary dressings for the arable rotation were not introduced until 1961, and it is probable that the lower potash status of these plots has affected to some extent the yields of the test crops of the arable rotation.

TABLE 2

Mean yields of leys, lucerne and permanent grass, and response to N (1956–60)

(cwt. dry matter/acre/annum)

	Mean yield		Response to N	
	Highfield	Fosters	Highfield	Fosters
(1) Grazed ley	29·3	24·2	4·1	1·7
(2) Conserved ley	65·4	53·9	16·6	12·7
(3) Lucerne hay	66·2	76·0	—	—
(4) Arable (seeds hay)	52·6	51·7	3·6	7·1
(5) Permanent grass (original sward)	29·1	—	6·3	—
(6) Permanent grass (reseeded)	30·0	29·1	4·4	0·1

Note: Rates of N tested were 0·15 *v.* 0·30 cwt./acre except for conserved ley, for which these dressings were applied *per cut* (average 5 cuts/annum), and seeds hay, for which the rates were 0·30 *v.* 0·60 cwt./acre.

Yields from leys and permanent grass 1956–60

Table 2 gives the yields of dry matter for the various leys and the permanent grass for the period 1956–60; the yield of the grazed

plots was estimated by sample cuts. There was on Highfield little difference between the yield of the original permanent grass, the reseeded grass or the grazed ley; each gave about 30 cwt. dry matter acre. An average starch equivalent for this material would be 60–65; assuming that three-quarters would actually be used by the grazing animal, the yield of " utilised starch equivalent " would be of the order of 15 cwt. acre. This is very similar to the mean yield of 15·5 cwt. starch equivalent acre in the previous experiment, which ran from 1937 to 1949 (Boyd *et al.*, 1949). The yield of the reseeded pasture on Fosters field has been very similar to that on Highfield, but the grazed ley has yielded about 20% less. The conserved ley received much more N than the grazed ley, and yielded two to three times as much dry matter. Lucerne gave much the same yield of dry matter as the conserved ley on Highfield, but more on Fosters; the yield of the third year of the lucerne ley on Highfield has been lowered in several seasons by attacks of *Verticillium* Wilt.

Table 2 shows that, apart from the seeds hay of the arable rotation, the responses of the leys and permanent grass to N on Highfield were 20–40 cwt. dry matter/cwt. N, a reasonable level of response from pasture of this type, whereas on Fosters field the N responses were much less. The lucerne ley received no N, but there is information on the residual effect of the test applications of N for the preceding test crops:

Response of first-year lucerne to N applied to test crops

	(cwt. dry matter/acre) Highfield	Fosters
After FYM for potatoes	2·3	−0·1
No FYM for potatoes	4·1	3·1

The increase was larger and more consistent on Highfield than on Fosters, and also where no FYM had been applied to the potato crop 2 years earlier.

TABLE 3

Mean yield of wheat (1st test crop) and response to N (1957–60)

(cwt. grain/acre)

	Mean yield Highfield	Fosters	Response to N * Highfield	Fosters
(1) Grazed ley	39·6	40·1	0·6	2·7
(2) Conserved ley	39·6	40·0	2·3	4·0
(3) Lucerne	42·7	46·2	2·2	2·9
(4) Arable	42·2	39·4	2·8	6·5

* 0·3 *v.* 0·6 cwt. N/acre.

Yields from the test crops

Wheat. Table 3 gives the mean yields of the first test crop, wheat, for the period 1957–60. The wheat yields were very similar for all four rotations and on both fields, the only exception being that after lucerne on Fosters field, which has given about 6 cwt. more wheat than any other. The mean yields are the average of two rates of N, 0·3 and 0·6 cwt. N/acre, and Table 3 also shows the average

responses to the extra 0·3 cwt. N. As might be expected, the responses were least for the grazed ley and greatest for the arable rotation, but on both fields the average yield at the high rate of N was less for the grazed ley than for any other rotation, and was highest after lucerne or three arable crops.

The experiment was modified in 1961 to allow four rates of N to be tested on wheat instead of two as in earlier years. The rates and responses obtained are in Table 4. On Highfield the average

TABLE 4

Wheat: Effect of N and rotations 1961

(cwt. grain/acre)

Rates of N (cwt./acre)	Grazed ley	Conserved ley	Lucerne	Arable
Highfield				
0·0	29·2	28·7	39·0	33·2
0·3	42·9	38·9	38·8	36·5
0·6	47·2	42·1	42·5	50·9
0·9	44·9	46·0	39·7	50·7
Mean	41·1	38·9	40·0	42·8
Fosters				
0·0	22·0	24·0	43·1	28·6
0·4	30·2	34·7	51·7	37·7
0·8	34·0	37·5	50·8	46·8
1·2	37·6	40·0	48·2	47·0
Mean	31·0	34·0	48·5	40·0

yields of wheat in the four rotations followed much the same pattern as previously, and differences were small. On Fosters the average difference between rotations was very much greater, although in the same general direction as in previous years, the grass leys doing particularly badly relative to the arable rotation and the lucerne ley particularly well. 1961 is the first year in which the response per unit N has been as high on Highfield as on Fosters. As expected, the wheat after the arable rotation gave very large responses to N, of the order of 15–20 cwt. of grain cwt. N, while the responses after lucerne were quite small on both fields. The responses after the grass leys, whether conserved or grazed, were also large.

Potatoes. Table 5 gives the average yields of the second test

TABLE 5

Mean yield of potatoes (2nd test crop) 1958–60

(tons total tubers/acre)

	Highfield	Fosters
(1) Grazed ley	16·4	15·8
(2) Conserved ley	16·4	15·8
(3) Lucerne	16·2	16·0
(4) Arable	14·9	14·7

crop, potatoes, in the period 1958–60. There was a small but consistent difference between the average yields on the two fields, those on Highfield being a little higher; with FYM or the higher rates of fertiliser, however, their yields were similar. Following the three leys, potato yields were almost identical, but after the arable rotation were less by more than 1 ton acre. As mentioned above, supple-

mentary dressings of K were applied to the conserved ley and lucerne rotations from 1955 onwards, but not to the arable rotation until 1961.

The original quarter plots testing N and FYM were subdivided to test the effects of P and K and check whether yields were being limited by a shortage of these nutrients, the PK interaction being confounded with quarter plots. Table 6 gives the mean responses

TABLE 6

Potatoes (2nd test crop): mean responses to FYM, N, P and K 1958–60

(tons total tubers/acre)

	Grazed ley	Conserved ley	Lucerne	Arable	Mean
Response to FYM (15 tons FYM/acre)					
Highfield	0·6	0·1	0·8	2·6	1·0
Fosters	2·2	1·4	2·0	2·1	1·9
Response to N (1·0–0·5 cwt. N/acre)					
Highfield	0·4	0·3	0·7	0·6	0·5
Fosters	0·7	0·7	1·0	1·4	1·0
Response to P (1·8–0·9 cwt. P_2O_5/acre)					
Highfield	0·4	0·5	0·0	−0·5	0·1
Fosters	0·6	0·4	0·2	0·7	0·5
Response to K (1·8–0·9 cwt. K_2O/acre)					
Highfield	0·4	−0·2	0·0	0·9	0·3
Fosters	0·1	0·4	0·3	0·0	0·2

to FYM, N, P and K for the period 1958–60; it should be noted that the responses are averaged over all other factors, those for fertilisers, for example, being the mean of plots with and without FYM.

The average response to FYM was 1·0 ton/acre on Highfield and 1·9 tons/acre on Fosters; potatoes in all rotations showed a good response on Fosters, whereas on Highfield only those in the arable rotation did. The sum of the mean responses to fertiliser without FYM, 1·4 tons/acre on Highfield and 2·5 tons/acre on Fosters, also indicated a greater need for plant-nutrients on Fosters. There were fairly large responses to the additional N, particularly on Fosters, and some response to additional P on Fosters. The average responses to additional K were small, but were larger without FYM on both fields.

In general, these results show that for all rotations, but particularly for the lucerne and arable rotations, yields when FYM was withheld were being limited by the low rates of fertilisers tested. Because of this the manurial scheme for most crops, including potatoes, was revised in 1961, and more fertiliser was applied to plots not receiving FYM. Unfortunately on Highfield in 1961 there was a very poor plant on many of the plots receiving FYM, and yields were obtained only for plots without FYM. Results for Fosters show that the mean yield from extra fertiliser almost exactly equalled that from FYM. On both fields the increased dressings of

fertiliser have eliminated the differences found in previous years between the arable and ley rotations.

Barley. The mean yields of the third test crop, barley, are given in Table 7. On Highfield the average yields are very similar after all

TABLE 7

Mean yield of barley (3rd test crop) and response to N (1959–61)

(grain at 85% dry matter, cwt./acre)

	Mean yield		Response to N	
	Highfield	Fosters	Highfield	Fosters
(1) Grazed ley	44·6	46·9	0·0	4·4
(2) Conserved ley	46·0	46·0	1·8	2·5
(3) Lucerne	45·2	48·2	−0·6	4·9
(4) Arable	47·0	43·9	4·2	5·6

Note: The rates of N were 0·0 *v.* 0·2 cwt./acre for Highfield and 0·2 *v.* 0·4 cwt./acre for Fosters.

four rotations, except that the arable rotation gave higher yields with N. On Fosters field the best yields were given by the lucerne, closely followed by the grazed and conserved leys; the yield from the arable rotation was somewhat less, and the difference was only to a small extent made up for by extra N.

Allowing for the basal dressing of 0·2 cwt. N/acre for barley on Fosters, the response per unit N was about five times as great on Fosters as on Highfield. Positive N responses were not obtained from the wheat and barley test crops on Highfield until 1955, and only recently have the responses become large enough to be economic. Until the 1961 wheat crop, the nitrogen responses on Highfield remained much smaller than on Fosters for all three test crops; however, as Table 2 shows, the leys and permanent grass responded more to N on Highfield than on Fosters.

Discussion

Much of the scientific value of an experiment of this kind lies in the physical, chemical and biological changes taking place in the soil with the different rotations, and effects on crop yields cannot be fully interpreted independently of these changes. The results described above, however, are sufficiently clear-cut to be of considerable interest in their own right. It is evident that, within the limited range of conditions tested, the yield from the test crops has not been materially improved by the preceding 3-year leys compared with normal arable cropping, and that where lower yields have been obtained after arable crops the difference can be made good simply by increased fertiliser dressings.

In assessing the significance of these conclusions it should be noted that the physical structure of the Rothamsted soil is particularly robust, and it is not therefore surprising that physical effects of leys have not apparently influenced crop yields. Moreover, the test is not a very exacting one, for the arable treatment crops themselves include a year of seeds hay; also, the grazed ley has been relatively unproductive, particularly on Fosters. It must also be remembered that the value of the ley in decreasing crop diseases when used as a

break in an intensive arable rotation is not tested in this experiment, as the six arable crops have been chosen so as to minimise the effect of disease in the comparison of rotations.

Information of the kind provided by this experiment is of value where assessing the relative economic advantages of the different systems. The alternative source of such information—surveys and farm costings—can provide reasonable estimates of the major costs for different systems of farming, but corresponding estimates of the relative returns from the different systems are bound to be suspect, because they are based on comparisons between farms and because a particular system tends to be associated with particular types of soil and with other variants of farming practice.

There will soon be further results from the series of ley fertility experiments, which are of a basically similar design to the Rothamsted experiment, on National Agricultural Advisory Service Experimental Husbandry Farms. These experiments include a test of the effect of 6- and 9-year leys.

Reference

Boyd, D. A., Crowther, E. M., Moffatt, J. R. & Yates, F. (1949). *J. R. agric. Soc.*, **110**, 104.

Field Plots Committee

by H. V. Garner

The original Rothamsted experiments consisted almost entirely of " Classicals " which, after a short formative period, almost ran themselves on a fixed annual schedule. A very simple organisation sufficed to keep the system working in field, laboratory and record office. Annual experiments began in a small way during the First World War, and by 1922 the number of annual plots had risen to 239, as compared with 205 classicals. Even at this stage the experimental programme was settled by a few interested people in the Director's room, but as the number and complexity of the experiments increased a more permanent body was needed. This was the beginning of the Field Plots Committee, whose responsibilities have gradually grown till now, with some fifty would-be experimenters and only about 350 acres of potential experimental land, several specialised bodies have been set up to make sure that experiments are statistically and agriculturally sound, that they are sited on suitable land and that both farm staff and experimenters know their respective responsibilities at every stage. Easy communication between the many individuals concerned with the field experiments is very necessary. This job falls on the Secretary of the Committee, whose office is the clearing house for all matters relating to the field experiments. The following notes give an outline of the development of the Committee since it was formed nearly 40 years ago.

In April 1922, at the suggestion of Sir John Russell, the Staff Council set up a sub-committee to consider the best method of making observations on the field experiments and permanently recording them. This body drew up a scheme of observations on insect and fungus attacks, incidence of weeds, habit of crop growth,

and physical and chemical soil characteristics. In due course heads of departments were asked to inform H. V. Garner, who had just been appointed to demonstrate the experiments, about the kind of observations required. So far as can be ascertained, there is no record that these early observations were ever made, but as several thousand visitors saw the fields in the summer months, this is perhaps not surprising. In the following year T. Eden, an ecologist, was appointed and E. J. Maskell was seconded from Imperial College to improve the accuracy of field experiments and make detailed quantitative observations on the plots. On 31 January 1924 a body called the Field Observation Sub-Committee first met. There was no list of members present, but H. J. Page, then head of the Chemistry Department, presided in the Director's absence and T. Eden was Secretary. The main business was to reconsider the original proposals for field observations, and this time the work was split up and assigned to the scientific departments. " It was recognised that H. V. Garner's chief contribution would be the collection of observations from visitors." The next three meetings were devoted almost entirely to observational matters, but at the 5th meeting, held in December 1924, the programme of annual experiments for 1925 was decided. It was also laid down by the Staff Council that departments wanting field experiments should work through the Secretary of the Committee. In the meantime R. A. Fisher had developed his statistical methods, which gave rise to the Latin square and randomised block designs, and the interest of the Committee began to move from observations to applying the new designs and experimental techniques to modern fertiliser problems, and in 1925 this new outlook was expressed by a change of name to the Field Plots Sub-Committee. In a minute dated October 1925 we read: " It was suggested that the question of the design of experiments should be given additional consideration in the light of Mr. Fisher's methods. The Secretary (T. Eden) reported that the Field Experiments department worked in the closest cooperation with Mr. Fisher, to whom all questions of principle were referred." The experiments of 1925 provided the first examples of the new designs to be published in the Station Report.

In 1926 Rothamsted took over the lease of the Woburn Farm from Dr. Voelcker, and arrangements for field experiments there also came under the Committee. In the following year several of the original members took up other posts, including T. Eden, who was replaced as Secretary by A. R. Clapham. Experiments at outside centres, which began in a small way in 1922 and had since been much extended, came under the Committee in 1928. It was in this year that E. M. Crowther joined the Committee and took a leading part in its activities till his death in 1954.

This period is marked by the beginning of three long-period rotation experiments, a four-course testing the residual values of organic and phosphatic fertilisers at Rothamsted and a six-course to study the seasonal action of fertilisers on both farms. These experiments, which lasted 25 and 30 years, respectively, were the first of their kind, and long-period rotation experiments are now part of the urniture of all permanent soil research stations. The minutes of those early meetings give very little indication of what went on

during the gestation of these experiments; there were isolated references to particular matters, but the deliberations which must have taken place before the experiments reached their final form were not recorded. In recent times much more information about decisions on complex experiments is on record in the Committee papers.

In 1930 A. R. Clapham left Rothamsted and D. J. Watson was appointed Secretary. By this time the amount of work passing through the Committee had reached a stage when a system of rules had to be drawn up for presenting proposed experiments to the Committee and the steps necessary to get them on the ground. An executive sub-committee consisting of E. M. Crowther (Chairman), R. A. Fisher, H. J. Miller (the farm manager) and D. J. Watson (Secretary) was appointed in 1931 to look at schemes before they went to the main committee. This body was very active and met about six times a year, with a corresponding decrease in the work of the main Committee; in 1933 F. Yates and J. R. Moffatt were appointed in place of R. A. Fisher and H. J. Miller. This arrangement lasted for 13 years, during which six long-period rotation experiments were started.

At the beginning of the War experiments at outside centres were greatly increased to study problems arising out of fertiliser shortages and substitute materials. This side of the work was taken over by the Chemistry Department to avoid overloading the Field Plots Committee, which already had an elaborate set of field experiments on war-time problems on both farms. Early in the War there was some anxiety about the original records, in view of fire and other risks. In the minutes of 15 July 1941 it is recorded that: "The Director said that arrangements had been made for Kodak's to make micro-photographs of the records of past experiments. One copy would be preserved at Washington and the other at Ottawa." Soon afterwards the risks diminished and this safeguard was not necessary.

At this period it appeared that most of the work was being done by the executive body, and the main committee met only two or three times a year to hear reports and discuss programmes. In 1944 both these bodies were dissolved and a single committee was appointed; it was the former executive committee, with the addition of F. C. Bawden and B. Weston, the field superintendent. It reported to the Staff Council.

There were still several administrative changes before the final form was set up in 1953 with E. M. Crowther (Chairman), F. Yates, H. H. Mann, D. J. Watson, J. R. Moffatt and H. V. Garner (Secretary). This body was made responsible to the Director, instead of to the Staff Council, but its reports were widely circulated. By this time the increase in the numbers and complexity of the experiments had begun to make heavy demands on the members, and meetings were very protracted. It was therefore decided to set up three working parties to prepare material for the main Committee, they were: Classical and Long-Period Experiments—Chairman, F. Yates; Agronomy Experiments—Chairman, E. M. Crowther; Pathology Experiments—Chairman, F. C. Bawden.

The mechanisation of experimental operations in the field and the increasing use of microplots and sampling methods led to the

formation of a Working Party on Field Methods under R. G. Warren. Meanwhile new fungicides, insecticides and weedkillers confronted experimenters with a fresh set of hazards, and a sub-committee on the Use of Noxious Materials was set up under D. J. Watson to advise the Committee. A Planning Group with G. W. Cooke as Chairman was formed to select experimental sites and supervise the manuring of non-experimental land, particularly areas being prepared for future fertiliser experiments. In 1959 G. V. Dyke succeeded H. V. Garner as secretary of the Committee.

A committee is generally an unloved thing, particularly one with some authority and a hand in so many peoples' affairs; but on the whole the scheme which developed at Rothamsted has worked, for in the last 40 years many hundreds of experiments have been laid down, and we still have a usable experimental farm.

THE FARMS

J. R. Moffatt

Rothamsted

In contrast to 1960, 1961 started with field work very seriously behind schedule. The mild and extremely wet autumn of 1960 made it impossible to drill much winter corn or beans, and 1960 ended with most of the potato crop still in the ground and very little land ploughed. The mild, wet weather continued into 1961, and hope for the 1960 potatoes was almost abandoned. However, in a fine spell in February some of the leeway was made up; potatoes were lifted, land was ploughed and some winter wheat sown. The early spring brought a welcome spell of dry weather, and land work forged ahead. The late ploughing, the lack of frost tilths and the lashing by rain, all combined to make it difficult to obtain good spring seedbeds. The summer was dry and field work was seldom interrupted. Crops grew well and conditions for harvesting cereals and roots were good. By the end of 1961, all winter cereals and beans were well through the ground and ploughing was almost complete.

The Effect of Weather on Crops

The autumn of 1960 was so wet that no winter beans were drilled and only a few small experimental areas of winter wheat; very little land was ploughed. January and early February 1961 continued mild and wet, but then in a 2-week spell of dry weather ploughing was continued and about 20 acres of winter wheat were sown. During March rain fell on only 5 days, and good progress was made. As a result of the late ploughing the soil was in a raw, unweathered state, and seedbeds were obtained only by many disc harrowings and rollings, but even then they were "cobbley". Most of the corn was drilled before the end of March, by when strong winds had dried out the ground, so the rain in early April was needed. The wet spell was prolonged, and the rain in April was 1·15 inches above average and fell on 21 days. This curtailed cereal spraying with herbicides, and potato planting, which was not finished until mid-May.

May was dry, with periods of strong winds. Spraying was further delayed, and the unkind soil dried into hard lumps which conventional implements could not break down. A rotovator produced satisfactory seedbeds, which might have been better had it been used direct on the ploughed land. Field work was up to date by the end of the month.

June and July were dry; the total rain for May, June and July was 2·8 inches below average. Weeds were easily controlled, silage and most of the hay was made under good conditions, and cereal crops maintained good growth throughout the period.

Rain fell on 18 days in August, and harvest work went on intermittently; a fine spell at the end of the month enabled the work to be finished early in September, but most of the corn had to be dried. Ploughing started early, and the ground ploughed up extremely well.

As there was very little late blight, potato haulm remained green until towards the end of September, and lifting conditions in October were good. Sugar beet continued to grow until they were lifted in November. Wheat drilling started early in October, and all winter wheat and winter beans were sown by mid-November. In December weather was very variable; spells of hard frost and heavy rain were interspersed with very mild spells. Frost was recorded on 12 of the 13 days between 17th and 29th, the hardest being 20° on the ground on the 29th. The year ended with a blizzard, during which 14 inches of snow fell.

By this time all the wheat was through the ground, the beet had all been cleared, dung had been ploughed in on 15 acres and most of the other ploughing was finished.

Field Experiments

The 1960/61 field experiments had a bad start because of the wet autumn and winter; many of the dates of planting had to be altered considerably, and spring wheat replaced winter wheat in several experiments. The heavy spring planting programme started in good time, but did not finish until mid-May; only one experiment had to be abandoned. All crops grew well, and damage by birds and other vermin was negligible, except in the High Field Ley–Arable experiment. No corn plots were lodged, and harvest conditions were reasonable; both potato and beet harvests were taken without difficulty, under excellent conditions. The modified forage harvester enabled 370 cuts from grass plots to be made quickly and efficiently.

Broadbalk is usually sown late to destroy, by cultivations, the initial germination of slender foxtail (*Alopecurus myosuroides*) and wild oats (*Avena ludoviciana*). The conditions in autumn and winter of 1960/61 were such that no satisfactory cultivations were possible before drilling in mid-January, and a very heavy infestation of slender foxtail resulted. The few wild oats were all pulled in 32 hours. The permanent wheat section was sprayed with TCB/MCPA. Weeds were plentiful on the rest of the field, especially so in Section V. The plant was regular but thin, and yields were below average. There was a good autumn germination of slender foxtail, so after cultivations the seed for the 1962 crop was drilled under excellent conditions early in November.

Hoosfield barley plots were sprayed twice with dalapon in autumn 1960 to control twitch (*Agropyron repens*), and in the autumn of 1961 only a few areas needed to be sprayed again. MCPA was used in spring on strips 1, 2 and 3 to control coltsfoot (*Tussilago farfara*), but strips 4, 6 and 7 were sprayed with CMPP, as the predominant weeds were chickweed (*Stellaria media*) and cleavers (*Galium aparine*). Only a few stunted coltsfoot plants survived. The policy of sowing the barley late, combined with hand

pulling of wild oats (*Avena fatua*), was continued; its success shows in the fact that all the wild oats present were pulled in 16 hours.

The new method of harvesting the Park Grass plots described in the 1960 Report was again used, and saved much time and labour.

The Hoos Half Acre wheat and fallow reverted to normal cropping after being modified for 4 years to facilitate studies on the wheat-bulb fly (*Leptohylemyia coaretata*).

Barnfield, the classical mangold field, was fallowed a second time in preparation for a new experiment in 1962; dung and fertilisers were applied as for a crop. Repeated rotary cultivations were given to eliminate any twitch still present.

The Exhaustion Land was sprayed in autumn 1960 with dalapon against twitch, and only plots 5 and 6 and part of 2 needed spraying in 1961.

Cropping

Of the 463 acres farmed, 297 were under arable crops or fallow, 104 under short-term leys or lucerne–grass mixtures and 62 were under permanent grass. The main arable crops were wheat (88 acres), barley (94 acres), oats (9 acres), beans (36 acres), potatoes (28 acres), and kale, sugar beet and swedes (13 acres). 29 acres were fallowed.

The cropping depends upon the requirements of the field experiments, both immediate and future, but the rotation is based on wheat, barley and either roots or beans. Potatoes are the main root crop, as sugar beet is unsuitable for our land and little kale is needed; the balance of the root break is sown to beans, which make little demand on labour. Arable fields are rested periodically under grass or lucerne—grass leys, which are usually left down for about 5 years.

This system is flexible and represents a compromise between the often conflicting demands of experiments on pests and diseases, which require uninfested fertile sites, with experiments on fertilisers, which require sites likely to show a response to different forms of any one fertiliser. Many fertiliser experiments can be catered for only by keeping some areas deficient in some nutrients; as these areas are seldom worth cropping, they are mainly kept under long-term leys or fallow.

Crops

Cereals

Most of the Cappelle and Professeur Marchal winter wheats were not sown until well into the New Year, and several areas were sown as late as mid-February. In one experiment, drilled on 13 February, three winter varieties each yielded over 50 cwt./acre at the highest level of nitrogen. Another experiment compared winter and spring wheats, both sown on 15 February; Cappelle gave a mean yield of 45·8 cwt./acre, and Jufy I a mean of 43·3 cwt./acre. The sowing of most of the spring wheat was delayed by weather until early March, but before the end of May it was better than the winter wheat, which at one stage looked as though it lacked vernalisa-

tion and might not come into ear. However, by mid-June the crop looked normal, and it came into ear about the end of the month.

The Jufy I spring wheat and the Proctor barley mostly went into rather rough seedbeds, and growth was retarded by the drought and cold winds in May. The barley, in particular, was uneven in growth and was yellow in patches, but all crops looked satisfactory by the end of June. They ripened evenly, and the quality and germination of all crops was excellent. The wheat averaged over 40 cwt./acre and barley about 40 cwt./acre.

All the cereals were sprayed with herbicides, mainly CMPP and TCB/MCPA. Spraying was delayed by rain and strong winds, but was quite effective.

Beans

All the spring beans were sown during March or early April, and most of the areas were sprayed immediately with simazine. They grew well in early summer and were sprayed with "Metasystox" to control bean aphis (*Aphis fabae*). As the dry weather continued into July, the plants lost vigour, though the set of pods seemed reasonable; they ripened earlier than usual and yielded about 25 cwt./acre.

Potatoes

During the year we harvested two crops—the 1960 crop in February and March, and the 1961 crop. The Majestics of the 1960 crop were mainly sound, but were caked with mud. The King Edwards and the Ulster Supreme, also very muddy, were damaged by blight and secondary rots. Most were sold to the Potato Marketing Board, but they were not required as ware, so sorting was not the problem it might have been.

The few early varieties were planted towards the end of March, but the start of maincrop planting was delayed until mid-April, and was not finished until the second week of May. Satisfactory tilths were obtained by using the rotovator. Majestic and King Edward VII were the main varieties, though there were a few Ulster Supreme. Drought restricted growth in the early stages, but the plants grew vigorously during July, August and September. Few cultivations were needed to control weeds, and there was little blight. The King Edward and Ulster Supreme were given a precautionary spraying, but the Majestics were not sprayed. The haulm was burnt off with concentrated BOV in late September, and lifting started towards the end of the month. Conditions were ideal until towards the end of the operation. The tubers were of nice size and shape, but there was some slug damage to the King Edwards. Both varieties yielded well considering the dry summer, the King Edwards giving about 15 tons/acre total produce and the Majestics rather more. Towards the end of picking stillages were used instead of sacks. These were loaded in the field, and unloaded and tipped at the farmstead by a special head fitted to the fore-end loader mounted on a tractor. This system requires fewer men for carting and stacking, and does less damage to the tubers.

Sugar beet, kale and swedes

These crops were all drilled early. Initially sugar beet grew slowly, and the shortage of labour made singling a protracted operation. The crop grew well in the late summer and autumn. The average yield was 16 tons/acre, with an average sugar content of 16·3%.

Both swedes and kale grew well, and weeds were easily controlled by a few cultivations. Very satisfactory yields were obtained.

Grassland

Pastures grew well in early March, but growth was slowed later by cold weather. Rapid growth was resumed in April, and cattle were turned out between 20 and 24 April. Cutting grass for silage started on 24 May, immediately corn spraying and potato planting was finished. Conditions were excellent, and the silage was of good quality.

The hay crops were lighter than usual, as recovery from early grazing was slow. Cutting started on 25 May, and most of the hay was made and carted in excellent condition. The lucerne–cocksfoot mixture gave three heavy cuts, the first and last of which were made into silage and the other into hay. All crops were bruised immediately after cutting by a forage harvester fitted with special blades. This accelerated the loss of moisture, especially from the stems of the lucerne plants.

The dry weather in May and June slowed down the growth of pastures and " keep " became scarce. Two applications of nitrogen improved the growth, especially after the rain in mid-July; at no time during the summer was grass plentiful, and the seeds undersown in the cereal crops proved invaluable in the autumn.

Livestock

Cattle

Eighty-three store cattle, bought in the autumn of 1960, were wintered in covered yards, and from January on were fed mainly on silage. In the dry summer the cattle kept the grass closely grazed, and when " keep " became scarce in early June some were transferred temporarily to Woburn. All but 12 of the cattle were sold fat by the end of December. Supplementary food was given after mid-October.

A further 63 young cattle were bought in autumn 1961. Silage was fed to them at grass from mid-November; in December they were brought into covered yards and fed on silage, brock potatoes and kale, with a little hay and straw, and a small allowance of home-produced concentrates.

The organophosphorus insecticidal wash used on the 83 young cattle in autumn 1960 against warbles was very effective. Of the 53 examined in April 1961, one had 2 mature grubs, and 3 had one mature grub each. All young cattle were treated in November 1961.

Sheep

The flock of 122 ewes was flushed on good grass before tupping in October 1960. The feeding of concentrates started 6 weeks before

lambing, and was gradually increased until the ewes were getting 1 lb. per head per day at the start of lambing. The ewes were in excellent fettle at lambing, when weather was good. There was a very good fall of 228 lambs, which gave a lambing percentage of 187. Two ewes died in the lambing field, and 3 lambs died from Pulpy Kidney disease, which made it advisable to inoculate all the lambs. The sale of fat lambs started early in June; 88 lambs needed for grazing experiments were sent to Woburn for over-wintering, and the balance was sold before the end of the year.

After drafting, 111 ewes remained in the flock, and to these 27 gimmers of our own breeding were added; these were flushed in autumn 1961 on undersown seeds. The feeding of hay started during the hard frosts about Christmas.

In the autumn the ewes were injected with one of the new combined vaccines to give immunity to a wide range of diseases, and they will be vaccinated again shortly before lambing. They were also dosed with a nematicide.

Equipment

New cattle- and sheep-handling pens include a cattle crush and weighbridge, a sheep spray race, dosing and drafting races, and footbath pens.

Buildings and Roads

About 1,400 yards of uneven tracks leading from the farmstead were made into gravel roads, and the area of concrete at the farmstead for parking cars was extended.

Staff

Mark J. Hill left in May on appointment as farm manager to Lord Belper. Roger Moffitt replaced him in July.

Woburn

Woburn also had a mild, wet autumn and winter, but with less rain than at Harpenden field work was less disrupted. However, no winter corn was sown and little land was ploughed by the beginning of the year. During the fine spell in February the ploughing was completed and spring beans sown. With only 4 rainy days in March, spring-corn sowing was finished by the end of the month. Seedbeds for all crops had to be forced, as the early ploughed land was badly lashed by rain and the late-ploughed dried rapidly into rock-hard clods, and the rotovator was invaluable for the purpose. By the end of March field work had got as far as was possible with the existing soil conditions; the early, and some of the maincrop, potatoes were planted, and some sugar beet was sown.

The welcome rain early in April softened the clods, which worked down into good seedbeds for sugar beet and carrots. The rotovator was needed again to prepare some heavy ground for potatoes, but planting was finished by the middle of the month. May was dry, but all crops grew well. Two wind frosts on 27 and 28 May severely

damaged the potatoes, and in the dry weather many of the earlies did not recover. Despite the dry weather through June and July, most crops made satisfactory growth, except that beans and sugar beet were checked in July.

The cereal harvest was interrupted by rain, but was finished by the end of August, and very little of the corn needed drying.

In a dry, mild spell at the end of September and most of October the potatoes and sugar-beet experiments were lifted in excellent condition. The heavy land was in such good condition that after surface cultivations it was drilled with winter wheat. November was rather stormy, but the sugar beet was all cleared before the end of the month, and the ground was later cultivated with a chisel plough. About 30 acres of light land were subsoiled before ploughing to break a pan about 15 inches below the surface. Ploughing was well forward by the end of the year, and would have been finished but for the spell of hard frost towards the end of December. However, during this spell all the dung was carted out and now awaits spreading.

Potatoes

The early varieties were planted about mid-March and grew rapidly, but they were severely damaged by two frosts in late May. Those on the two Green Manuring experiments in Stackyard Field were hardest hit and failed to recover, but other experiments made a partial recovery. The early-planted King Edwards and the Majestics recovered and grew well in the latter part of the season. A precautionary spraying against late blight (*Phytophthora infestans*) was given to the King Edwards. The haulm was burned off in mid-September, and lifting started before the end of the month. The average yield of maincrop was 12 tons/acre with tubers of good size and shape; however, common scab (*Actinomyces scabies*) was so widespread on some areas as to make much of the crop unsaleable.

Sugar beet

Most of the beet was drilled early and germinated rapidly. It was sprayed with DDT against leaf miner (*Pegomyia betae*) and with "Metasystox" against sugar-beet yellows. Some experimental areas were badly damaged by hares after singling. In July the crop wilted in the hot weather, but continued to grow well into the autumn. There was a late attack of sugar-beet yellows, which, though widespread, was not severe. The roots cleaned easily and the yield averaged about 14 tons/acre of washed beet with a sugar content of 15·6%.

Market-garden crops

The leeks grew well in the autumn, and lifting started in mid-February, some weeks earlier than usual. Yields were about average. The crop planted in 1961 grew well, and lifting would have started before the end of the year had the ground not been frozen.

The red beet germinated very irregularly, and some plants appeared through the ground only at the end of June, when others

were about 4 inches high. At both times of harvesting plant numbers differed greatly, even on duplicate plots of the same treatment.

Cropping

Of the 127 acres farmed, 18 carried wheat, 38 barley, 4 beans, 23 potatoes and 7 sugar beet. There were small areas of rye, lucerne, carrots and market-garden crops. Temporary grass occupied 16 acres and permanent grass 4 acres.

Crops

Cereals

The only winter wheat was sown on the Classical wheat and barley experiment in Stackyard field in mid-January. It was so badly damaged by birds and lashed by rain that it was cultivated up and spring wheat sown. Jufy I was the only spring wheat, and Proctor the main barley variety, but some Herta and Plumage Archer was grown on long-term experiments. All crops were sown early but in rather unkind, forced seedbeds. "Avadex" successfully controlled wild oats (*Avena* spp.) in barley in Broad Mead I, and all crops were sprayed with herbicides. The barley was a little patchy in growth and colour in May, but by June all crops looked remarkably well. The nitrogen given suited the season, and no crops lodged. A spring wheat experiment was attacked by *Fusarium*, but elsewhere yields of spring wheat and barley averaged about 26 cwt./acre.

Beans

Beans, sown on light land early in spring, grew well in early summer, but by July were suffering from the drought; the plants lost vigour and turned yellowish, and the lower leaves dropped off. On the Irrigation experiment the vigour of the plants increased with the amount of water given, and this is reflected in the yields, which ranged from 13·3 cwt./acre on the non-irrigated plots to 28·8 cwt./acre on those fully irrigated. A light attack by bean aphids was controlled by one early spraying with "Metasystox".

The carrots in the Ley–Arable experiment were disappointing; they suffered from drought and virus disease, though sprayed twice with "Metasystox".

Grassland

The 20 acres of grass carried the overwintering tegs until mid-April, when it was manured and shut for hay. It was cut in early June, and although it took 10 days to make because of dull weather, the quality and yield of hay were good. Nitrogen was applied three times to encourage the aftermath, which was grazed by bullocks and sheep from Rothamsted. At no time was the grassland very productive. The grazed ley on the Ley–Arable experiment was also less productive than usual, and on the Irrigation experiment only six cuts were taken.

Livestock

Cattle and sheep

The tegs for the 1961 grazing experiments at Rothamsted and Woburn were overwintered at Woburn. Sugar-beet tops were fed in early winter and hay in late winter. In July more lambs were transferred to Woburn for overwintering.

Fifteen Hereford bullocks from Rothamsted grazed for $3\frac{1}{2}$ months in the summer, but no cattle were bought until the autumn. The 14 then bought were fed on beet tops, brock potatoes and straw, but when they were brought in to covered yards just before the end of the year they were given hay and a cereal–beet pulp concentrate ration.

Pigs

The herd of pigs was brought down to 12 of the Large White sows plus 14 home-bred gilts. Fewer pigs than usual were sold. The litter size at weaning improved, and should improve further with the use of farrowing crates.

WOBURN EXPERIMENTAL STATION

C. A. Thorold

H. H. Mann, Assistant Director, Woburn Experimental Station, from 1928 to 1956, died on 2 December. His association with Woburn Experimental Farm began in 1895, when he was appointed to assist Dr. J. A. Voelcker, Consulting Chemist to the Royal Agricultural Society, and he was the first resident research chemist at the laboratory and pot-culture station built in 1898. He left in 1900 to become Scientific Officer to the Tea Association of India, where he was later Principal of the Poona Agricultural College and Director of Agriculture, Bombay State.

Air frost on the mornings of 27 and 28 May (minima −2·2° C., −0·6° C.) damaged the foliage of early and maincrop potatoes. Within the last 10 years, a similar late frost has occurred only in 1956, when early potatoes were affected. Rain in May, June and July was below average (Table 1), but in spite of seemingly unpropitious conditions for crop development, yields in general were satisfactory, except for some early potatoes.

Table 1

Monthly mean temperatures (means of maximum and minimum), total rainfall and daily means of bright sunshine for April to October 1961 (departures from long-period means in brackets)

Month	Main temperature (° C.)	Rainfall (inches)	Bright sunshine (daily mean) (hours)
April	9·7 (+1·7)	2·30 (+0·37)	2·82 (−2·09)
May	10·5 (−0·4)	0·63 (−1·57)	6·70 (+0·66)
June	14·5 (+0·4)	1·26 (−0·44)	7·19 (+0·58)
July	15·4 (−0·9)	1·49 (−0·95	5·46 (−0·58)
August ...	15·8 (0·0)	2·50 (+0·17)	5·32 (−0·54)
September ...	15·3 (+1·7)	2·31 (+0·28)	4·21 (−0·42)
October ...	10·6 (+0·9)	2·96 (+0·66)	3·83 (+0·44)

Field Experiments

Continuous wheat and barley land

Strips of winter wheat (Squarehead's Master) were drilled across the "continuous wheat and barley" areas, in the same positions as this crop occupied in 1959 and 1960. The young plants were badly damaged by birds in February, and the dry period in March (0·12 inches rainfall) seemed to check growth and impede recovery. The crop was ploughed in, and the strips were resown with spring wheat (Jufy I) on 22 March. Plumage Archer barley was drilled on 9 March in the strips occupied by barley in 1959 and 1960. Both wheat and barley yielded less than in 1960. Table 2 shows the decline in yields since 1959, the first year after fallowing, and that

in each year barley has done better on the old wheat land than on the barley land, and wheat better on the old barley land.

TABLE 2

Mean yields of grain and straw (cwt./acre) in plots 1, 7 and 11b of "continuous wheat" and "continuous barley" areas in 1959, 1960 and 1961

	Continuous wheat area				Continuous barley area			
	Wheat		Barley		Wheat		Barley	
	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw
1959 ...	20·5	27·2	23·1	16·1	26·1	35·1	21·6	13·3
1960 ...	19·6	27·4	21·9	16·8	25·6	36·0	19·9	13·4
1961 ...	10·4	16·3	19·2	10·9	11·0	14·4	14·0	7·5

Take-all (*Ophiobolus graminis*) is now widespread, and barley roots were also attacked by *Fusarium* spp. Because of this, neither wheat nor barley will be grown on the "continuous wheat and barley" areas in 1962, but spring oats, which will be harvested by plots to measure any residual effects of previous cropping with strips of wheat and barley.

Ley and arable rotations experiment

The 1960 Report drew attention to the greater yield response of sugar beet to farmyard manure at 15 tons/acre than to fertiliser providing nitrogen and potash. This happens when sugar beet follows 3 years of arable crops or 3 years of cut lucerne, but not when it follows a 3-year grazed ley. Differences between the amounts or availabilities of potash supplied by fertiliser and by farmyard manure may account for the relative superiority of dung, and this is being tested by attempts to equalise the potash levels of the soils in the treatment and test periods. Only when this is achieved, will it be possible to decide whether other factors are concerned.

The tops of Majestic potatoes were blackened by the air frosts, but it seems they recovered well, because yields were up to average. In 1961 there were eight potato plots in Block 2, constituting the first-year treatment crop of the 3-year arable rotations, which have previously been regularly followed by 2 years of test crops (1st test crop—potatoes in period 1938–55, sugar beet in period 1956–61; 2nd test crop—barley in period 1938–61). The four "continuous arable" plots in Block 2 (No. 17–20) have had nine potato crops (five treatment plus four test crops) in the period 1939–61, and the other four plots, where ley and arable rotations alternate (No. 21, 22, 27, 28), have had seven (three treatment plus four test crops). The eight 1961 plots have not carried potatoes in the period 1957–60. There is no recorded damage to maincrop potato foliage by frost in this experiment, so it is worth comparing the 1961 yields with the means for the period 1939–56, in an attempt to assess effects of frost on tuber production. The mean yield of the eight plots in 1961 was 12·4 tons/acre, and the general mean for these plots from 1939 to 1956 was 11·0 tons/acre. Only one plot (No. 17) yielded less in 1961 (9·6 tons/acre) than the mean in the preceding period (9·8 tons/acre). On 30 May 1961 this plot was noted as having leaves severely

damaged by frost, but another plot (No. 18) in a similar state yielded 11·9 tons/acre in 1961, the same as the mean yield for this plot in 1939–56. Yields of the other six plots (No. 19–22, 27, 28) damaged by frost in 1961 exceeded their past mean yields.

Although the yields of Majestic were not obviously affected by frost damage to foliage, those of Ulster Chieftain in the Green-Manuring Experiment almost certainly were. The mean yield of this early variety was less than 2 tons/acre, and no plot yielded more than about 2½ tons/acre. Plots after both ryegrass and trefoil green-manure crops which had been undersown in the preceding barley crop yielded slightly more (0·23 tons/acre) than others.

Irrigation experiment

The twenty-four plots of Arran Pilot potatoes in the Irrigation Experiment were not uniformly affected by frost. Eight at one end of the area were little harmed, when foliage in the other plots was severely "scorched" or blackened, but these differences did not affect tuber yields detectably. However, this may be because responses to irrigation, fertiliser and cultivation treatments were large. Table 3 shows the mean yields of irrigated and unirrigated plots at two levels of nitrogen.

TABLE 3

Mean yields of potatoes (tons tubers/acre) with and without irrigation, at 0·6 and 1·2 cwt. nitrogen/acre

Cwt. N/acre	Without irrigation	With irrigation	Mean
0·6	5·31	10·26	7·78
1·2	5·93	12·64	9·29
Mean	5·62	11·45	8·54

Usual cultivations for potato crops were compared with minimum cultivations plus simazine weedkiller applied at 2 lb. in 40 gallons/acre on 31 March, 2 weeks after planting. As in 1960, plots which received "normal cultivations" yielded better, this time on average 3 tons tubers/acre more.

The irrigated plots of Italian ryegrass were given "Nitro-Chalk" at 0·3 or 0·6 cwt. nitrogen/acre before each of the six cuts, but unirrigated plots were not given fertiliser before the fifth cut, because the fertiliser seemed unlikely to be taken up without rain or irrigation. Soil moistures at three depths (0–3 inches; 3–9 inches; 9–18 inches) were measured on one irrigated grass plot and on one nearby unirrigated grass plot in March, before irrigation started and after each cutting. Only the measurements at 9–18 inches, where moisture changes are particularly interesting, will be considered now. Table 4 shows that growth of the grass without irrigation declined after the second cutting on 15 May, and was negligible (2 cwt./acre) between 15 June and 14 July. Within this period the rainfall was 1·41 inches, and soil moisture at 9–18 inches was only 4·8%. Irrigation equivalent to 3 inches of rain maintained the level of production per month at about 13 cwt./acre and increased the soil moisture at 9–18 inches from 8·0 to 10·0%.

The mean yield of the Italian ryegrass, with and without irrigation, was 62·3 cwt./acre, compared with 95·7 cwt./acre in 1960.

TABLE 4

Mean weights (G) of dry Italian ryegrass (cwt./acre) and soil moisture (S/M) as percentage of the weight of samples taken at 9–18 inches, in irrigated and unirrigated plots

Date of cut	Without irrigation G	Without irrigation S/M	With irrigation G	With irrigation S/M
18 April	12·8	9·2	11·9	10·4
15 May	19·9	8·4	20·1	9·6
15 June	3·6	4·8	13·3	8·0
14 July	2·0	4·8	13·8	10·0
14 August	3·8	4·4	11·5	10·0
11 September	3·3	4·0	8·7	7·2
Total	45·4		79·3	

Established in the autumn of 1959, some plots deteriorated during 1961, and yields contained from 12 to 39% of their dry weight as *Poa annua*. The plots were therefore ploughed, after the sixth cut on 11 September.

Table 5 shows the response of Herta barley to irrigation and two levels of nitrogen. As previously, increasing nitrogen gave a greater mean response (7·2 cwt. grain/acre) than did irrigation equivalent to $3\frac{1}{4}$ inches rain (4·9 cwt. grain/acre).

TABLE 5

Mean yields of irrigated and unirrigated barley (cwt. grain/acre) at two levels of nitrogen (0·2 and 0·4 cwt. N/acre)

Cwt. nitrogen/acre	Without irrigation	With irrigation	Mean	Difference
0·2	23·3	29·0	26·2	7·2
0·4	31·3	35·4	33·4	
Mean	27·3	32·2	29·7	

Difference 4·9

Unirrigated spring beans gave a mean yield of 13·3 cwt. grain/acre, compared with 28·8 cwt. grain/acre with "full" irrigation equivalent to $4\frac{1}{2}$ inches rain; the mean yield was 21·3 cwt. grain/acre when 3 inches were applied between 23 June and 1 August, and 18·7 cwt. grain/acre when $1\frac{1}{2}$ inches were applied between 19 May and 7 June. Crops unirrigated or irrigated only between 23 June and 1 August matured earlier than the others, and were harvested by combine on 12 August, 9 days before the others.

Market-garden experiment

An experiment with market-garden crops was started at Woburn in 1942, on light, sandy soil considered to be exhausted and which might be expected to be improved by incorporation of organic materials. Responses to different organic manures were compared with inorganic fertilisers. From 1942 to 1950 there was a 2-year rotation, with leeks after green peas in the first year, and cabbages after globe beet in the second. Peas were omitted in 1951, since when only three crops have been taken in the 2-year rotation. From 1956 onwards, early potatoes replaced cabbages. Manuring has changed from time to time, but since 1956 it and cropping systems have been constant, and so yields in this period can be considered to indicate the general trend of manurial responses.

Four organic manures are compared, namely: farmyard manure alone, and composted with vegetable refuse; sewage sludge alone, and similarly composted. Two levels (10 and 20 tons/acre) of each were applied for every crop, with and without inorganic nitrogen (0·3 cwt. N/acre). Some plots without organic manures receive " Nitro-Chalk " at three levels (0·3, 0·6, 0·9 cwt. N/acre), and all plots receive basal dressings of P and K at 0·3 cwt./acre.

Table 6 shows that organic manures have given higher yields than inorganic fertilisers, particularly of globe beet.

TABLE 6

Mean yields of leeks (dressed), globe beet (" bulbs ") and early potatoes (total tubers) in tons/acre, associated with certain manurial treatments in the Woburn Market-garden experiment, in the 5-year period 1956–60

Treatment	Leeks	Globe beet	Early potatoes
Farmyard manure at 20 tons/acre (no " Nitro-Chalk ")	5·7	10·9	7·8
Sewage sludge at 20 tons/acre (no " Nitro-Chalk ")	5·1	7·3	7·1
" Nitro-Chalk " at 0·9 cwt. N/acre ...	4·0	4·0	6·4
No " Nitro-Chalk "	2·9	1·7	4·0

Farmyard manure at 20 tons/acre, with or without inorganic nitrogen, gives largest yields, and basal P and K without inorganic nitrogen the smallest.

Analyses made by the Chemistry Department show that much P has accumulated where farmyard manure and sewage sludge have been applied. The farmyard manure plots also have much K, almost a constant amount at three sampling depths within the range 0–24 inches. Therefore the lower yields obtained with inorganic fertilisers may partly reflect inadequate amounts of P and K. The position as well as amount of nutrients may also differ between plots given organic and inorganic manures, for the organic manures are ploughed in, whereas the basal fertiliser and " Nitro-Chalk " are broadcast after ploughing. The experiment has now been re-designed, to test higher rates of fertilisers applied both before and after ploughing, and future results should show whether factors other than the nutrients in farmyard manure improve the crops. Because sewage sludge is inferior to farmyard manure, it will be omitted from the comparison, and no more sewage sludge or sludge compost will be given.

DUNHOLME FIELD STATION

R. Hull

S. N. Adams left to become Soil Chemist at the Hobart, Tasmania, Station of the Commonwealth Scientific and Industrial Research Organisation. He contributed to the 24th Congress of the International Institute of Sugar Beet Research in Brussels in February and R. Hull to the joint meeting of the same organisation with the American Society of Sugar-beet Technologists in London in May.

Experimental work at Dunholme ended with the completion of the field experiments in December. Dunholme Field Station will close in 1962 and the staff and equipment transfer to new laboratories at Broom's Barn Farm, Higham, near Bury St. Edmunds. This move and the resulting staff changes restricted experimental work this year. Field experiments were continued on the same subjects as last year, and the British Sugar Corporation gave invaluable help with them and with surveys of diseases and pests.

Broom's Barn Farm

After delay and difficulties from wet weather and mud during the winter, Tilbury Construction Co. Ltd. completed the roads, services and farm buildings in June, when Kerridge & Co. Ltd. immediately started work on the laboratories and houses, due for completion in May 1962. By the end of 1961 the six houses were finished and three were occupied. Most of the laboratory buildings were roofed and internal work was progressing rapidly.

The 280-foot-deep borehole did not yield enough water for irrigation, so on the recommendation of the Geological Survey it was deepened to 390 feet. Pumping at 11,500 gallons/hour for 12-hour periods on three consecutive days in July dropped the water level from 117 to 174 feet, where it remained constant. This yield of water will irrigate 2 acres at a time.

The land was divided into ten fields of 10–23 acres, mostly rectangular, and an area near the buildings was reserved for small plots. The outfall from the roadside drainage ditch proved inadequate, and water often spilled over the land at the north end of the farm, so it was led into a large soak-away. After the wet and mild winter, tilth was poor, especially where the soil had been compacted and puddled when harvesting sugar beet. The spring-sown wheat and barley in these fields was patchy, with the bad patches apparently caused by anaerobic conditions about 6 inches below the soil surface. Autumn-ploughed land ran and set; it grew weeds profusely and was ploughed again in spring.

The crop rotation was designed to clean the land from perennial and annual weeds, especially wild oats. Each field will be cropped in turn with oats and tares, cut for silage in June, and then fallowed and worked. Twenty-two acres were sown with S.53 meadow fescue for seed, and other fields will have red clover or seeds mixtures in

rotation with wheat, barley and sugar beet. In 1961, 30 acres of barley yielded 16–18 cwt./acre of grain, 17½ acres of spring wheat yielded 20–24 cwt./acre, 16 acres of oats yielded 16 cwt./acre. The spring-sown beans failed because of weeds and bird depredations. Twenty-nine acres of sugar beet yielded 14·2 tons/acre of roots at an average sugar content of 15·7%.

In the autumn 35 acres were sown with winter wheat, and most of the land was ploughed by the end of the year.

An experiment was started in August to assess the effect of subsoiling on various crops. Other long-term experiments will begin when the land has been cleaned and levelled. This year's sugar-beet experiments tested the use of insecticides for controlling yellows, yellows-tolerant varieties, chemical weed control, seed inoculation with *Azotobacter* and the effect of sowing date and nitrogen on growth throughout the season.

Incidence of aphids and virus diseases

Myzus persicae again lived during the winter of 1960/61 on wild beet on the Suffolk coast. Beet mosaic spread from wild beet to mangolds and sugar beet on the Shotley peninsula; there was no evidence that yellows did. Mosaic was more prevalent in beet crops throughout eastern England than for many years.

Green aphids infested sugar beet early in May. Cold winds and frost in May restricted their increase temporarily, especially in Norfolk and south Lincolnshire, and elsewhere they were patchily distributed. Infestations reached an average for the country of 1 per plant by 20 June, and then increased to an average of 3 per plant (20 per plant in Ipswich and Spalding factory areas) by 8 July when counts ceased. The most heavily infested areas were the west Midlands, Isle of Ely, Suffolk, Essex and south Lincolnshire. This early infestation led to yellows showing early and threatened another severe attack of the disease, the fifth in consecutive years. *Aphis fabae* infestations were light and late.

Spray warnings were sent to growers by some factories in the second week of May, about 2 weeks earlier than in 1960, and by the end of June nearly all growers had been advised to spray, some twice or three times. About 329,000 of the 410,000 acres of sugar beet were sprayed with systemic insecticide, and of this sprayed acreage 113,000 was sprayed twice and 15,000 three times. 52,000 acres were first sprayed in May, 215,000 in June and 62,000 in July; some growers delayed spraying after receiving the spray-warning because black aphids were few, and they still do not appreciate the significance of the less obvious and generally fewer green aphids.

Mean incidence of yellows in 143 sample fields at the end of June, July, August and September was 0·7, 10·4, 21·2 and 25·1. This is a slower rate of development of yellows than given by comparable aphid infestations in 1949 and 1957. With no spraying in 1949 and late spraying in 1957, the September incidence of yellows was 50–60%.

The crop started early and grew rapidly until mid-summer, but soil temperatures in summer were too low for maximum growth. Nevertheless, the country's final yield of 14·5 tons/acre of roots at 15·4% sugar content has been exceeded only in 1960.

Aphids on sugar beet

During May and early June 1960, ninety-one samples of aphids were collected from sugar beet in all English beet growing areas. Fifteen per cent of samples contained alate *Myzus persicae*, 40% *Macrosiphum euphorbiae*, 34% *Aphis fabae*, 9% *Aulacorthum solanii* and 29% other species. The corresponding figures for apterae were 19, 10, 5, 1 and 2%. *Myzus ascalonicus*, the commonest species in samples from weeds, was not found in these samples from sugar beet.

In the glasshouse, apterous *Hyperomyzus lactucae* L., *Megoura viciae* (Buckt.), *Microlophium evansi* (Theob.) and *Myzus* (*Sciamyzus*) *cymbalariae* Stroyan failed to transmit sugar-beet mosaic virus; *Acyrthosiphon pisum* (Harris) did transmit but inefficiently. *M. persicae* and *Myzus ascalonicus* Donc. (from *Stellaria media*) were equally efficient vectors of yellows, *Macrosiphum euphorbiae* (Thos.) (= *M. solanifolii* Ashm.) from potato was less efficient than *M. persicae*, and *M. cymbalariae* from Chinese cabbage much less. Alate and apterous *A. fabae* infected fewer plants with yellows than alate or apterous *M. persicae* under the same conditions, but plants inoculated with yellows ("N" strain) by 1, 3 or 5 *M. persicae* or *A. fabae* had equally severe symptoms.

Coccinellid predators were active in March on spindle colonised with *A. fabae*. Insecticide treatment did not prevent coccinellids from recolonising sugar beet at Broom's Barn once aphid numbers had increased again, and the coccinellid population in August was estimated to be 57,000 adults/acre on the commercial crop sprayed twice with demeton-methyl. Although coccinellids were fewer at Rothamsted, they kept the aphid population in check. (Dunning and Heathcote.)

Mangold clamps

The field staff of the British Sugar Corporation surveyed the incidence of aphids in mangold clamps in beet-growing areas at the beginning of April and of May 1948–57. Over this 10-year period the average number of clamps per square mile ranged from 1 to 2·1 in April and 0·4 to 0·9 in May, with 5–53% and 11–62% of clamps infested with aphids in April and May respectively. A similar survey over 855 square miles in late April 1961 covered 2,750 farms; of these, 1,482 grew mangolds, red beet or fodder beet, and 962 still had clamps, of which 443 were aphid-infested. The aphids on shoot samples from 123 infested clamps were identified in the laboratory; 63% of the samples contained *Myzus persicae*, 2% *M. ascalonicus*, 3% *Macrosiphum euphorbiae*, 9% *Aulacorthum solanii*, 96% *Rhopalosiphoninus staphyleae* and 17% *R. latysiphon*.

Collaborative work with Imperial College Field Station and the Plant Pathology Laboratory of the Ministry of Agriculture continued on the control of aphids in mangold clamps by methyl bromide fumigation. Two clamps near Lincoln had a 3-inch diameter perforated ventilating pipe along the centre of the base and fine-bore polythene sampling tubes built in during clamping. One clamp was of normal triangular cross-section, $6 \times 10 \times 45$ feet covered with straw, alongside an identical control clamp; the other was a cube

8 × 13 × 25 feet enclosed in straw-bale walls. In early March these clamps were fumigated to find the rate gas injected along the ridge was distributed through the clamp, and the rate it dispersed after the polythene covering sheet was removed. Feeding the gas mixed with air into the clamps from a mist blower gave very uneven distribution. The clamps aired very rapidly after removing the sheet, and the built-in ventilation pipes were unnecessary. The approximate total CTP'S (concentration of gas in oz./1,000 cu. ft. × time in hours) resulting from three fumigations in each clamp were 117 and 52 respectively, and they did not damage the mangolds or sprouts.

Four aphid-infested clamps in Cambridgeshire and West Suffolk were fumigated between 18 and 21 April. Their volumes were 2,000, 3,600, 3,700 and 8,000 cu. ft., and their dimensions, covering material, mangold variety, condition and temperature differed. The target CTP was 100, and means of 118, 103, 100 and 69 were achieved. Aphids were all killed in the first three clamps, but reinfested two of them by mid-June. One of these was heating (15–24° C.) when fumigated, and partly collapsed a week later. The inlet pipes were too short to cover the large top of the fourth clamp, dimension 6 × 30 × 48 feet, and the gas was unevenly distributed; one corner reached a CTP of only 26, and some aphids survived there. (Dunning.)

Tolerant varieties

Varieties selected for tolerance to yellows at Dunholme, the Plant Breeding Institute, Cambridge, and by Dr. S. Ellerton of Bush-Johnson were compared with four commercial varieties on sprayed and unsprayed plots at Broom's Barn. Mean yellows incidence on the sprayed plots in August was 35% and on the unsprayed 55%; mean root yields were 19·0 and 17·7 tons/acre; mean % sugar 16·5 and 16·0; mean sugar yield 62·8 and 56·8 cwt./acre. Reselections from the Dunholme tolerant varieties A7S/2, M9S/6, N4S/1 and Q1S/1 outyielded the commercial varieties on both the sprayed and unsprayed plots, on average by 11, 19, 7 and 19% respectively. Multiplications of the varieties 93/1, 103/233, 20/30, which did well in 1959, again outyielded the commercial varieties by 6, 7 and 9% on average, but varieties 337/45, 45/694 and 11/21 gave 99, 102 and 92% of the yield of the commercial varieties. Varieties 337/6S, 337/8S and 5/430 outyielded the commercial ones by 7, 10 and 8% respectively. The five PBI varieties also outyielded the commercial ones by 14, 11, 7, 2 and 5% and two of the five Bush-Johnson varieties did so by 13%. Most of these best-yielding varieties outyielded the commercial ones on both the sprayed and unsprayed plots. (Hull and Glenister.)

Insecticides

Four field trials tested the effect on yellows incidence of insecticide sprays normally used to control pests such as mangold fly, flea beetle and pigmy beetle. The spray in early May was, on average, 3 weeks before the local spray warnings, and 5 weeks before the farmer sprayed the field, including the trial area, with whatever

systemic insecticide he favoured. The insecticides, oz./acre of active ingredient, and mean percentage decrease of yellows incidence as infected-plant-weeks were: DDT (16) 1·3%, demeton-methyl (7) 23·7%, dieldrin (6) 12·0% and dimethoate (1·2) 14·7%; trichlorphon (6) gave 9·5% increase. Either killing predators of aphids or disturbing the first few viruliferous aphids may be the reason for trichlorphon increasing yellows incidence; all other insecticides decreased yellows on average, but only demeton-methyl did so at all four sites. Dimethoate and demeton-methyl had unexpectedly large effects considering the very few aphids found at the time of spraying.

Five field trials made in co-operation with the British Sugar Corporation tested the effect on yellows incidence of commercial and experimental aphicides applied at the time of the local spray warning. Of thirteen materials tested only five were used at all sites. At the three sites examined after spraying, all insecticides controlled black aphids and all except fluoroacetamide controlled green aphids. The incidence of yellows on the control plots was: 87% at Holbeach (18 August), 87% at Cambridge (26 August), 17% at Sleaford (16 August), 24% at King's Lynn (25 August), 64% at Saffron Walden (2 August). At all sites most materials greatly decreased yellows incidence; exceptions were dimethoate (10% decrease at King's Lynn) and fluoroacetamide (decreases of 8·5% at Holbeach, 6% at Sleaford, 1% at Saffron Walden and an increase of 8% at King's Lynn).

The percentage decrease of yellows incidence expressed as infected-plant-week totals were: demeton-methyl 50%, dimethoate 36%, fluoroacetamide 16%, menazon 41% and phosphamidon 52%. Comparing these results with those of previous years shows that some materials behave differently in different seasons. Formulation changes of menazon and fluoroacetamide may be responsible. Bulking the results of 2 trials in 1959, 4 in 1960 and 5 in 1961, the decreases they gave in yellows incidence were: demeton-methyl 35%, dimethoate 27%, fluoroacetamide 16%, menazon 31% and phosphamidon 31%.

Except for phosphamidon and " Disyston " at King's Lynn, all insecticides increased sugar yield; the greatest increase at each site was: Holbeach—phosphamidon 27%; Cambridge—dimethoate 27%; King's Lynn—demeton-methyl 9%; Saffron Walden—demeton-methyl 17%. Yields were not determined at Sleaford.

At Gleadthorpe Experimental Husbandry Farm, Notts., 9 plants with yellows were transplanted into the centres of plots of beet $\frac{1}{36}$ acre in area, and each of the plants was infested with 20 apterous *M. persicae* 8 days before the plots were sprayed with various insecticides. It was intended to measure spread of yellows from the infectors, but this was prevented by a heavy natural infestation of green and black aphids. Nevertheless, plots differed greatly in losses from aphid attack and yellows; yields in cwt. sugar/acre from plots treated with insecticides were: demeton-methyl 47, dimethoate 47, fluoroacetamide 39, menazon 48, DDT 32, indopol polybutene 30, " Disyston " 54; unsprayed plots containing infectors yielded 28 and without infectors 42 cwt./acre.

Granular formulations of aphicides were compared with demeton-

methyl sprays in the field. Trials at Broom's Barn and Sprowston tested early, and early + late sprays of demeton-methyl, seedbed applications of " Disyston " and menazon granules, and foliage top-dressings of " Disyston ". Seedbed application of " Disyston " on 23 March, worked-in before drilling on 10 April, controlled aphids in late May, but only halved the population in mid-June. All treatments except menazon decreased yellows incidence considerably; a seed bed dressing of " Disyston " followed by an application to the foliage in late May was best.

A trial on limestone soil at Dunholme tested " Disyston " granules side-placed into the soil with a " Gandy " granule applicator fitted with special coulters, either at the time of drilling or of steerage hoeing. These treatments were compared with a demeton-methyl spray and with " Disyston " granules applied to the foliage by the " Gandy " mounted on the steerage hoe, so that the plants retained some of the granules and the remainder fell on the soil in a 4-inch band. At 32 oz./acre (active ingredient) " Disyston ", side-placed at drilling on 15 April, gave poorer aphid and yellows control, but increased yield more than the 6-oz. rate. The " Disyston " foliar top-dressing (16 oz./acre) and the demeton-methyl spray (7 oz./acre), applied on 6 and 7 June, respectively, rapidly controlled aphids. The top dressing affected aphids for longer, decreased yellows more and increased sugar yield considerably more than did the spray. " Disyston " granules side-placed into the soil at the same rate and time acted more slowly, but gave the most persistent aphicidal action and decreased yellows and increased sugar yield nearly as much as the demeton-methyl spray.

" Disyston " and menazon granule formulations of various sizes and concentrations were applied as top dressings at 16 oz. active ingredient/acre, and compared with a demeton-methyl spray. All treatments except menazon controlled black and green aphids within 4 days. The large-sized 5% " Disyston " granules (formulation 4909a) controlled aphids and yellows less well and increased yield less than the normal-sized 5% granules (formulation 4909). Menazon 5% granules gave better aphid control than 0·5%, but decreased yellows and increased yield less; 10% " Disyston " was superior to the 5% and 2·5% formulations in controlling aphids and yellows, but increased yield less. The granules of higher concentration could not be applied as uniformly as those of lower concentration.

The efficacy of granules applied to the foliage may depend on the high dose given, and effect of varying dose was tested at Broom's Barn. Sprays were applied on 26 May in a 7-inch band over the row at 2 oz. a.i./acre and at 24 oz. a.i./acre, to compare exactly with the dose of insecticide in the granule treatments. The granules were applied at 24 oz. a.i./acre to the foliage and adjacent soil in a band of the same width, on 28 May. All treatments, except phorate spray at the 2-oz. rate, controlled green aphids well; phorate and dimethoate sprays and granules gave excellent control at the 24-oz. rate. Menazon granules at 12 oz. controlled green aphids better than the spray at 2 oz., but less well than at 24 oz. Yellows control paralleled the aphid control, although phorate granules at 24 oz. a.i./acre were slightly better than the spray at the same rate. Each

insecticide as a spray at the 24-oz. rate gave slightly better sugar yield than the granule formulation; the plants, which had seven leaves, were still rather small for retaining granules. (Dunning and Winder.)

At Broom's Barn the time of spraying with demeton-methyl (7 oz. a.i./acre) was compared with foliar top dressing with phorate granules applied at a rate of 13·7 lb./acre (22 oz. a.i.) with a " Horstine Farmery " granule applicator. The granules increased yield by 2½ ton of roots/acre, the two demeton-methyl sprays increased yield by 2 tons, and a single spray by about 1 ton/acre. At harvest all insecticide-treated plots had about 90% of plants with yellows and untreated plots 97%, but during July percentage infection was twice as great in the untreated plots.

The Harpenden trial compared untreated plots with those sprayed with demeton-methyl at the time of the spray warning, plots receiving seedbed application of granular " Disyston " (2 lb. a.i./acre), and others receiving top dressings of granular " Disyston " (1½ lb. a.i.). Aphids were few, even on the untreated plots. All treatments decreased yellows incidence by 10%. The top dressing of " Disyston " decreased yellows slightly less than either soil-applied " Disyston " or the spray of demeton-methyl—possibly because of the drought at the time of application, which prevented insecticide from being absorbed by the beet plants.

At Broom's Barn and Harpenden first infections were with sugar-beet mild yellows virus, and although sugar-beet yellows virus came later, it was less prevalent than the less-virulent one. (Heathcote.)

In seven trials in 1961 a foliar top dressing of " Disyston " granules, at an average rate of 22 oz. a.i./acre, decreased yellows incidence by 51%, compared with 30% by a standard demeton-methyl spray.

Seed crops

Seed crops had few plants with yellows in 1961; the mean incidence in sugar beet and mangolds was 2·9% and 7%, and the highest in individual crops 15% and 34%, respectively. Downy mildew was prevalent, particularly in crops raised under mustard cover, whether transplanted or grown-on *in situ*; up to 19·2% of plants were infected. A few plants with silvering disease were found in three mangold seed crops in South Lincolnshire and Essex.

Yellows was rare in sugar-beet stecklings in the autumn of 1961. Only one bed had more than 1% of plants with yellows and the average for those certified for planting was 0·14%. Twenty-six of 120 mangold steckling beds had more than 1% yellows; average yellows incidence in the remainder was 0·25%.

Spread of downy mildew from seed crops to nearby root crops has recently caused serious damage and, as the disease is usually more prevalent in seed-growing areas than elsewhere, special measures were taken against it in steckling beds this year. The average incidence in open beds, beds raised under mustard cover and those under cereal cover was 0·54%, 0·27% and 0·005%, respectively. Beds with the most infections were either destroyed or plants from them were transplanted in the autumn, so that those with mildew

will die during the winter and the disease will not spread as it does with undisturbed plants close together. (Byford.)

Downy mildew

Although fungicidal sprays sometimes decrease downy mildew in root crops and stecklings, their effects are inconsistent. At Dunholme three sprays with maneb, the first shortly after brairding, gave 4% of sugar beet with downy mildew in late August compared with 14% of unsprayed plants, 5% for " Perenox " and 7% for triphenyltin acetate, " Dithane " and " PP645 ". All sprayed plots gave a slightly greater yield of roots of higher sugar percentage than unsprayed. In a similar experiment at Pointon, Lincs., 2·7% of unsprayed plants had mildew in late July, whereas those sprayed with " Dithane ", triphenyltin acetate, " Perenox " and " PP645 " had 0·2, 0·5, 1·1 and 0·9% of plants with mildew respectively.

At Oundle, Northants., one, two or three sprays with triphenyltin acetate on sugar beet, the first applied after the mildew had appeared, decreased incidence in late July to 23, 20 and 17% respectively, compared with 37% in unsprayed plots. The crop later suffered from drought. The sprays increased sugar yield by 7·4, 11·9 and 10·8% respectively compared with unsprayed plots; the sprays increased sugar by 0·8%. The root juice purities for the unsprayed and once-sprayed plants were 85% and 83% and for the twice and three times sprayed 87% and 88%—effects very important for extracting sugar in the factories.

The same fungicides and " Strepospray " gave poor control of mildew when sprayed at 15- or 30-day intervals on August-sown stecklings at Dunholme.

The spread of the disease to a root crop surrounded by infected second-year plants, and its effect on yield of roots, was studied at Dunholme. Plants were marked as they developed downy mildew and their yield determined in November (Table 1).

TABLE 1

Effect of downy mildew on sugar beet

Date infected	% of plants infected	Average root weight (g.)	Sugar (%)	Sugar per root (g.)	Sugar per root as % healthy
May... ...	7·0	262	15·6	40	31
June ...	14·8	224	13·9	31	24
July ...	5·4	462	13·5	62	49
August ...	5·2	614	14·5	89	70
September/ October ...	4·0	812	16·8	136	107
Healthy ...	—	754	16·9	127	100

Plants infected in June had smaller roots and sugar percentage than those infected in May. Plants infected in July and August also had a lower sugar percentage but larger roots. Plants infected late in the season were slightly heavier, on average, than healthy roots, and their sugar percentage the same. Only 8% of plants which contracted mildew in May had mildewed leaves in June, but 42% of those that apparently recovered developed mildew later.

Half the plants infected in June recovered by July, but 41% of these developed mildew later. This re-infection or redevelopment of the disease had little additional effect on yield. Plants infected in June, July or August which soon recovered weighed less than those which showed symptoms over a longer period. Most infected plants survived to harvest, but of those infected in May, June and July respectively 9·7, 2·8 and 1·3% died. Some of the survivors were very severely stunted; the roots of some plants infected in May and June weighed less than 25 g. in November. (Byford.)

Ramularia leaf spot

During the wet summer of 1960 Ramularia leaf spot defoliated some sugar-beet crops in Devon and Cornwall by August. Although the trouble does not usually develop so early, it occurs most years. Experiments done in co-operation with Mr. C. E. Loweth of the British Sugar Corporation tested the effect of fungicide sprays and of different varieties on the incidence of the disease.

Triphenyltin acetate and zineb sprays in July, August and September gave better control than "Perenox", maneb or "PP645". A spray with copper oxychloride at the end of July had no effect on the incidence of the disease on 23 October, but mid-August and early September sprays considerably decreased its incidence.

Mr. B. Crombie of the Irish Agricultural Institute, at Thurles, kindly supplied seed of four varieties of sugar beet selected for resistance to Ramularia leaf spot in Ireland, where the disease is prevalent. On 23 October varieties 191A and 185 had leaf spot, but much less than Sharpes E. Variety 155/1 had very little leaf spot, and variety OFG 228/1 had none, but considerable rust. The Irish varieties were outstandingly green and vigorous compared with the brown, drab appearance of Sharpes E. They gave yields of 65–86 cwt./acre of sugar, compared with 66 for Sharpes E and 81 for Sharpes E sprayed with fungicide. Their sugar content was 16·2–16·8%, compared with 15·2% for Sharpes E and 15·7% for Sharpes E sprayed. These preliminary results indicate that considerable benefit might result in crops in the south-west from spraying with fungicide and choosing appropriate varieties. (Hull.)

Seed treatment

All the gravity-separated, rubbed seed graded to $\frac{8}{64}$–$\frac{10}{64}$ inch supplied by the British Sugar Corporation to growers in 1961 was disinfected with ethyl mercury phosphate (EMP) steep treatment. It gave good brairds, which several fieldmen reported free from black leg. Machinery to treat the seed was specially designed to protect the operators. Of the total of 1,726 tons of seed supplied to growers, 847 tons of natural and 536 tons of rubbed seed graded to $\frac{7}{64}$–$\frac{11}{64}$ inch had a combined fungicide/insecticide dust treatment. 343 tons of rubbed seed graded to $\frac{8}{64}$–$\frac{10}{64}$ inch had the EMP steep treatment and was then dusted with insecticide. In 1962 the rubbed seed of all grades will have the EMP steep treatment.

In eighteen field trials the most effective seed treatment was EMP solution applied at 5% volume to weight in the "Mist-O-

Matic " machine followed by drying; this gave 28% more seedlings than untreated seed. "Agrosol" increased stands by 24% and "Panogen" by 23%. EMP steep, "Mist-O-Matic" fungicide, "Agrosan" dust and EMP applied in the "Mist-O-Matic" machine at 1% v.w. increased stands by 20, 20, 19 and 11% respectively. BHC dust applied to commercial EMP-steeped seed had no effect on seedling stand, but dieldrin applied as dust, liquid or mist, and heptachlor dust, gave less seedlings than seed treated with fungicide only, while heptachlor liquid applied to EMP-steeped seed gave less seedlings than the untreated control.

In 3 years' trials "Panogen" and "Agrosol" proved, on average, slightly superior to dust treatments. Liquid insecticide treatments sometimes depress seedling emergency. (Byford and Dunning.)

At Dunholme EMP steep increased seedling emergence in the field by 59%, and "Agrosol" and phenyl mercury acetate used as steep increased it by 49% and 40%, respectively. Five short-wet treatments with volatile compounds increased seedling emergence by 43–55%, and "Agrosan" dust increased emergence by 31%. EMP solution applied as a spray at 1% v.w. of liquid was more effective than 6%, when neither batch of seed was dried before sowing. "Agrosol", applied after the seed had been soaked in water for 20 minutes and dried, gave fewer seedlings than when applied to unsoaked seed in eleven out of thirteen seed samples. The increase in emergence in two samples was small and, on average, the water-soak decreased field emergence by 10%. (Byford.)

Two replicated field trials tested nine insecticide treatments on EMP-steeped seed at sites with wireworm populations of 150,000 and 400,000/acre. Seed rates were 4·3 and 4·1 lb./acre of $\frac{8}{64}$–$\frac{16}{64}$-inch seed respectively. Heptachlor liquid and dieldrin mist treatments decreased seedling emergence. (Dunning.)

Sugar-beet Manuring

This report gives the more important results of a series of field trials done in co-operation with the field staff of the British Sugar Corporation in 1960; the results of the 1961 experiments are not yet known.

NPK-dung trials

Nine 3^3 factorial experiments tested 0·6, 1·2 and 1·8 cwt. N/acre as ammonium sulphate; 0, 0·5 and 1·0 cwt. P_2O_5/acre as superphosphate, and 0·8, 1·6 and 2·4 cwt. K_2O/acre as muriate of potash both with and without dung.

Without dung, 0·6 and 1·2 cwt. N/acre were equally profitable, phosphate was uneconomic and the best potash dressing was 1·6 cwt. K_2O/acre. As in previous years, the highest rate of nitrogen depressed sugar yield. With dung, 0·6 cwt. N/acre was the best dressing, phosphate was uneconomic and 0·8 and 1·6 cwt. K_2O/acre were equally profitable. Dung gave a higher sugar yield than any combination of mineral fertiliser on a light soil in Nottinghamshire. These trials ended in 1960.

NK–salt trials

This series of experiments was designed to measure the response curve of sugar beet to salt and the nitrogen–salt and potash salt interactions; eight experiments tested all combinations of:

(*a*) 0·6 and 1·2 cwt. N/acre as ammonium sulphate;
(*b*) 0, 2 and 4 cwt. agricultural salt/acre;
(*c*) 0, 1·2 and 2·4 cwt. K_2O/acre as muriate of potash.

TABLE 2

The effect of salt on the response of sugar beet to nitrogen and potash. Mean of eight experiments in 1960

	Sugar yield (cwt./acre)				
	Cwt. N/acre		Cwt. K_2O/acre		
	0·6	*1·2*	*0·0*	*1·2*	*2·4*
Without salt	57·7	58·5	56·6	58·0	59·6
With 4 cwt. salt/acre ...	60·3	62·9	63·2	60·8	60·8

Table 2 shows that salt increases response to nitrogen but decreases response to potash. Without salt, 1·2 cwt. N gave only 0·8 cwt. sugar/acre more than did 0·6 cwt. N/acre. With 4 cwt./acre of salt, the difference was increased to 2·6 cwt. sugar/acre. By contrast, a response of 3·0 cwt. sugar/acre to 2·4 cwt. K_2O/acre without salt changed to a depression of 2·4 cwt. sugar/acre with 4 cwt. salt/acre.

Top-dressing trials

This series of nine experiments measured the effect of delaying some nitrogen until singling time. Treatments giving 0·6, 0·9, 1·2, 1·5 and 1·8 cwt. N/acre as sulphate of ammonia were compared with plots receiving the same total amount of nitrogen but partly as either 0·3 or 0·6 cwt. N/acre as " Nitro-Chalk " at singling time.

The total amount of nitrogen given and not the time of application was important for yield of sugar and tops. 1·8 cwt. N/acre applied to the seedbed depressed plant population, and a higher plant population was obtained by splitting such a heavy dressing. In spite of this, the split dressing did not give more sugar. (Adams.)

SOIL SURVEY OF ENGLAND AND WALES

D. A. Osmond

E. M. Bridges and D. V. Jones resigned, and were succeeded by D. J. R. Manley and E. M. Thomson, respectively. A. V. Vann was appointed to take charge of the Proline mechanical soil corer, which has proved satisfactory and has aroused great interest. C. C. Rudeforth returned from Pakistan and started work at Aberystwyth, where a new centre was established.

D. A. Osmond visited Rome, Ghent and Athens in connection with the production of the Soil Map of Europe being prepared by a Working Party of F.A.O. Surveyors from the North of England visited southern Scotland to correlate the soils on Carboniferous drift on each side of the border, but the heavy contamination, for example, by igneous rocks, of the Scottish drift makes correlation difficult. J. Muir (Soil Survey of Scotland) and B. W. Avery were requested to study the classification of British soils in the light of European and American classifications published recently.

Several surveyors gave lectures, arranged courses and field demonstrations, provided material for exhibitions and surveyed areas at the request of official bodies. Six visitors worked in the field for various periods with surveyors. The Cartographic Section produced maps and many diagrams, as well as continuing the preparation of maps for publication.

Eighty sq. miles were surveyed at 1 : 63,360 and 1,430 sq. miles at 1 : 25,000 on a reconnaissance basis; special surveys at various scales necessitated the mapping of more than 50 sq. miles.

Northumberland

Sheet 77, 7th Series (Hexham)

Surveying was concentrated in the south-west and the east central parts of the sheet. Over much of the south-west the mapping units previously established proved adequate, but in the valley of the East Allen a dark-grey, compact, tenacious drift deposit outcrops in many streams, particularly in their upper reaches. It varies from a laminated, silty clay to a very compact, stony clay, does not weather readily and shows little or no evidence of oxidation; any visible soil formation is confined to the upper 6–9 inches. Roots rarely penetrate below about 9 inches and only a poor vegetation is carried. When closely examined it gives the impression of water deposition, and in some places there are sand and silt partings suggesting deltaic conditions. Near Knock Shield, where the sands are best developed, a very strongly cemented iron pan ($\frac{1}{4}$ inch thick) occurs at the base of the sand parting and directly above a clay band.

Much of the lower (700–800 feet) east-facing slope of Allendale is covered by the drift overlain by glacial and post-glacial deposits of

Carboniferous origin. Its presence significantly affects the overlying soil, as it impedes drainage and limits profile and root development. Occasionally similar deposits occur in the West Allen valley as far eastwards as the Font valley at Mitford, where they are buried beneath the reddish-brown coastal drift.

The east central area, characterised by its gently rolling relief, merges into the Northumbrian plain at 400–500 feet. It is covered by a clay drift with few stones, usually giving clay loam and silty clay loam soils with impeded drainage. The soils appear to be derived mainly from Carboniferous material and to have a fairly high inherent fertility; calcium carbonate frequently appears below 27 inches. Some larger depressions still carry basin peat, which formerly may have been more widespread.

Occasional hills of Carboniferous formations, usually capped by a sandstone, protrude through the drift and often support birch scrub. The soils, particularly on crest and edge sites, are podzolised, with gley soils surrounding them, but where cultivated the podzols have lost most of their characteristics. (Ashley and Suggett.)

Yorkshire

Sheet 71 (Selby)

The remaining areas of this sheet proved no less complicated than the rest. Everywhere several thin superficial deposits occur sporadically and contribute to a pattern so intricate that only the very great importance of cash crops, which are strongly influenced by soil differences, justifies the separation of soil series.

Allerthorpe Common and its surroundings may be taken as typical. Fluvio-glacial sands, giving soils of the Stockbridge and related series, are overlaid by low mounds, which were probably dunes, of finer sands giving soils of the Holme Moor Group, whereas some of the deeper channels have flinty sands over flint gravels. Marling has been very important, and local opinion ascribes great and continuing benefit to it. Before reclamation the commons are very acid, and doubtless the primary crop response is to the lime in the marl. To what extent its clay content controls blowing and confers physical and chemical benefits to the soil is less clear and is being investigated. The black sands, i.e., podzols, are said to be more responsive than the brown sands or humus-deficient brown earths, which need careful treatment in the early years after marling if the marl is not to move down the profile too quickly. This suggests that a clay–humus complex has to be formed before the clay acquires stability. There is evidence that marled sands are more prone to develop a plough pan than unmarled sands; this may be associated with the high silt content of the marl.

A somewhat similar pattern occurs at Heslington, where the parent materials appear to rest on a gently undulating surface of boulder clay, all but the higher points of which are covered by fluvio-glacial sands and lighter morainic drifts. Slight rises therefore may have soils that are heavy, poorly drained and less easily cultivated than those surrounding them, or may be mounds of blown sand. The accompanying changes of height are usually scarcely perceptible to the unpractised eye.

Reconnaissance survey was continued on Sheet 90, 7th Series (Wensleydale), where 50 sq. miles were mapped between Settle, Arncliffe and Grassington. The most widespread soils are those over Carboniferous limestone, and include shallow rendzinas, brown earths of high base status, acid brown earths and podzols with thin iron pan. Preliminary studies suggest that only the rendzinas have developed from the limestone, the other soils having received extraneous material of both glacial and aeolian origin. Above 1,500 feet are the Yoredale sandstones, shales and limestone, which are mainly covered by a variable thickness of peat, except on the steeper slopes, where erosion prevents its formation. Above these rocks, at about 1,800 feet, the soils are mainly brown earths and podzols developed over Millstone Grit. (Crompton and Bullock.)

Lancashire

Mapping on a reconnaissance basis was continued on Sheet 94, 7th Series (Blackpool), east of a line Garstang–Lancaster, and about 175 sq. miles were covered in which no new association was recognised.

The survey of the Lowland mosses at 1 : 63,360 is complete, and land-utilisation maps have been prepared by the Agricultural Land Service. The total area of 51,000 acres has been divided into arable and grass (42,000 acres), scrub land (3,900 acres), woodland (1,450 acres), peat cutting (1,400 acres), under reclamation (250 acres) and other uses, e.g., tipping sites, golf course, etc. (2,000 acres).

Soil maps were prepared of the Halsall Estates (5,230 acres) for the Church Commissioners and of the holdings of the Lilford Estates around Tarleton and Much Hoole (5,105 acres). (Hall and Folland.)

Derbyshire

Sheet 125 (Derby)

The survey of the sheet was completed when 20 sq. miles were mapped in the parishes of Annesley, Felley and Silston in Nottinghamshire and Riddings in Derbyshire. All the soil series encountered have been described in earlier Soil Survey Reports. The field maps were prepared for the Cartographic Section, and an extended legend was prepared showing the relationship of the soils within major soil groups. Detailed descriptions were made, and samples were taken from representative profiles for use in the memoir; altogether seventy-seven profiles were sampled. (Bridges.)

Shropshire

The description and sampling of soils required for the memoir on Sheet 166 (Church Stretton) was completed.

The Forestry Commission's request for soil information to aid the preparation of working plans necessitated visiting many woodlands in Shropshire, Herefordshire, Staffordshire and Worcestershire; the information will also be of use as the reconnaissance survey in the West Midlands is extended. Some 80 sq. miles were

mapped, mainly in Clun Forest, where the soils are predominantly developed on Head or other drift of very local origin. Soils derived from the underlying Ludlovian and Downtonian rocks are of subordinate importance and differ from soils on rocks of the same age east of the Church Stretton fault. Above 1,300 feet soils somewhat similar to the Manod series are formed on Ludlovian rocks and derived Head. At similar elevations peaty gley podzols and peaty gley soils sometimes occur on finer-textured redistributed material, but at lower altitudes sols bruns acides are dominant.

A reconnaissance survey was made of 25 sq. miles near Orleton, Herefordshire, for the Agricultural Land Service, in connection with a proposed site for a new town. (Mackney and Burnham.)

Cambridgeshire

Sheets 173 (Ely), 174 (Thetford) and Sheet 135, 7th Series (Cambridge)

With the surveying of 45 sq. miles the reconnaissance survey of Sheet 173 (Ely) is almost finished. Most of the work was done south and east of March, but areas were also surveyed at Beck Bow, Soham Fen, Welney and the Bedford Level Washes, near Feltwell Anchor, and smaller areas elsewhere. Near March, on raised ground, Stretham, Wicken, Aldreth and Milton soils were mapped, but most of the work was in the adjacent fenland, where fen " clay " and rodden " silt " complexes predominated, although Midelney soils occur around Christchurch, east of March. Near Stonea is a complex sequence of peaty and humose gley soils of medium texture, developed on boulder clay, which has not been previously seen.

Detailed mapping continued on Sheet 174 (Thetford) in the outlying parts of the Forest, where plantations at Mildenhall, East Harling, Croxton and Wretham were surveyed. In addition, Swaffham Forest and King's Forest, Bury St. Edmunds, both outside Sheet 174, were also surveyed. In all 45 sq. miles have been covered, and the survey of the State woodland of about 80 sq. miles in the Brecklands, mainly of Corsican and Scots Pine, is now complete.

The soil pattern is generally similar to that observed previously, most soils being formed on the Chalk and sand mixture forming the Gipping Till. Humus podzols (Santon series) and brown earths (sols lessivés) of the Worlington series occur on raised flat ground; complexes of shallower soils, such as rendzinas (Newmarket series), brown calcareous soils (Methwold series) and brown earths (Worlington series), occur on slopes and valley sides. In King's Forest rolling ground predominates, mainly with soils of the latter group and no Santon soils.

Mildenhall Forest is a small block adjacent to the River Lark and the Fens; in addition to the slope soils, humus podzols (Santon series) and brown earths (Feckenham series) occur on gravels and associated blown sands, and gley soils and organic soils in the lowest parts. A somewhat similar sequence occurs between Croxton and Great Hockham, north-east of Thetford, where an extensive, discontinuous gravel strip, 4 miles wide and 1 mile long, runs in a north-easterly direction. The Santon series and brown earths (Redlodge and Feckenham series) are plentiful, but on the lower ground, with

an irregular, hummocky relief, gley soils and organic soils may appear in the hollows. (Hodge, Seale and Corbett.)

Cardiganshire

Sheet 127, 7th Series (Aberystwyth)

Part of the lower land near Aberystwyth had been mapped some years ago, and with the establishment of a new centre the soil series then used were appraised together with those used in North Wales on similar parent materials derived from Silurian and Ordovician rocks. An additional 53 sq. miles was surveyed at 1 : 25,000, a soil map was made of the College Farm, Aberystwyth, at 1 : 63,360, and the map of the Welsh Plant Breeding Station was revised. From the information thus obtained the applicability of the previous soil series was assessed.

The division of parent materials into those derived from hard and soft shales is not considered satisfactory, although hard and soft bands alternate in the solid shale, and are thought to result largely from texture variations in the original sediments. The areas of soils described as having hard and soft shales respectively as parent materials do not consistently correspond with recognisable hard and soft shale deposits. The explanation for the slight texture and colour differences that occur is probably to be found in a study of the site characteristics which reflect geomorphological history and drainage conditions. Work has started on the micromorphology of these soils. (Rudeforth.)

Bedfordshire and Hertfordshire

Sheet 147, 7th Series (Luton and Bedford)

The reconnaissance survey was continued, and a further 150 sq. miles were completed mainly north of a line joining Shefford and Royston. In the Biggleswade market-garden district the soils are mainly coarse textured, and are often stony where overlying the gravels of the Ivel and the glacial sands and gravels of the Southill–Broom district; the last are somewhat thin, and clay usually occurs within 3 feet of the surface. Small areas of very acid, sandy soils formed on the Lower Greensand occur around Rowney, Warden and Sandy Warren.

To the north-west, where these drifts overlie Oxford Clay, heavier and more poorly drained soils occur in Northill and Moggerhanger, but the higher ground is occupied by rather better-drained calcareous clay loams and clays of the Hanslope series associated with Chalky Boulder Clay. This series, one of the most widespread, also covers all the higher ground between Dunton and Wimpole. To the south-east the ground falls sharply to the Cam valley, which is cut in the Gault and is fairly free from drift; imperfectly and poorly drained, olive-brown clays and clay loams of the Wicken series are dominant.

As the land rises to the main mass of the Chalk, very calcareous grey clay loams and silty clay loams with imperfect drainage occur on the Chalk Marl between Guilden Morden and Whaddon. Farther

south, between Steeple Morden and Royston, the flatter areas on the Chalk are covered with freely draining, brown, calcareous soils formed on loamy drifts; the more rolling country around Limlow Hill and Morden Grange Plantation is characterised by soils of the Icknield series. (King.)

Hertfordshire and Essex

Sheet 148, 7th Series (Saffron Walden)

Reconnaissance surveying was continued in north-west Essex between Braintree, Haverhill and Saffron Walden, where about 200 sq. miles were completed. Most of the soils were satisfactorily grouped in the associations previously described, but additional associations needed will be described later.

Over much of the area, the Chalky Boulder Clay is more than 100 feet thick, and the derived soils (Hanslope association) cover both plateaux and valley sides, with only minor differences in profile characteristics. Along the deeper valleys river down-cutting has breached the Chalky Boulder Clay to expose Glacial Gravels and, occasionally, London Clay. The aspect of the valley sides is particularly important in soil-mapping. On east-facing slopes the gravel outcrop is usually masked by finer-textured Head mainly derived by periglacial mixing of boulder clay and gravel, whereas many west-facing slopes have coarse-textured soils developed directly on Glacial Sand and Gravel.

River alluvium is fine-textured, calcareous, high in organic matter and more or less gleyed. Where these soils are taken into arable cultivation dressings of manganese salts were beneficial, and soils of coarser texture at the base of the gravels, where springs are thrown out, appear to respond similarly. These soils are also calcareous and have a very dark-coloured A horizon which is conspicuous on ploughland; under semi-natural conditions they are recognisable by the dense cover of rushes and marsh marigold (*Caltha palustris*). (Thomasson.)

Glamorgan

With the surveying of 350 sq. miles, between the Swansea Valley in the west and the Rhymney Valley in the east, the reconnaissance survey of the county is complete. The Coalfield may be described as a series of concentric radial ridges and valleys rising towards the highest point, Cefn Fford (1,969 feet), near Hirwaun on the north crop. The soil-distribution pattern is governed mainly by topography, elevation and lithology (interbedded sandstone and shale) in an area of high rainfall.

Shallow peaty gley soils under Molinia occur along the crests; the upper slopes carry podzols under Nardus or Vaccinium, and shallow podzolised soils carrying bracken occur on the lower steeper slopes. The pattern is frequently interrupted by deep peaty gley soils, covered by Molinia, sedges and mosses, where the shale outcrop is extensive. Forestry Commission land (e.g., Rheola Forest) is concentrated in such areas. Where the relief and lithology permit, peaty gley soils are continuous along the valleys. Some drift is

always present, and where it is abundant, non-peaty, bouldery gley soils occur in the valleys. Similar soils are formed after restoring opencast mining sites, and where they replace deep peaty gley soils the land is upgraded for agricultural purposes.

The main effect of the increasing elevation is the formation of concentric zones of soils centred on Cefn Fford, the zones being characterised by overlapping but different combinations of soils. Thus, freely drained sedentary soils and deeper drift soils occurring on ridges and in valleys chiefly south of the Coalfield are the best local agricultural soils. The next inner zone tends to contain more podzolised soils in addition to these brown earths; in the next, podzols and shallow peaty gley soils are more extensive, and around Cefn Fford are extensive deep peaty gley soils and small areas of acid peat. The north and south margins of the Coalfield are delimited by an E.–W. depression containing peaty gley soils on shale, extensive areas of former mine workings, particularly around Merthyr Tydfil, and of opencast mining or restored land. (Crampton.)

Berkshire

Sheet 268 (Reading)

Mapping was continued at the scale of 6 inches to 1 mile, during which 36 sq. miles were surveyed in a rectangle with Sonning, Reading, Bradfield and Goring at the corners.

The district is crossed by the Thames, Kennet and Pang, and contains the dry valley formerly occupied by the Kennet. The two main land forms of plateau surfaces and valley floors are separated by moderately steep slopes with outcrops of bedrock that influence soil development. The commonest outcrops are of Upper Chalk, with Middle Chalk in the north and Reading Beds and London Clay in the south. Away from the slopes superficial deposits predominate.

Except for small outliers of Reading Beds, the plateau surfaces above 300 feet are covered by a diverse formation commonly containing many flints and far-travelled stones with a red-mottled clay matrix. This suggests that it may be the remnants of a soil, developed in a warm climate with distinct wet and dry periods, which was greatly disturbed during Pleistocene glacial periods; the main type of soil formed now is brown earth with gleying. On plateau sites below 300 feet are well-sorted fluviatile gravels with smaller, more rounded stones. Freely drained brown earths showing well-defined clay migration dominate, but where the gravels overlie Tertiary rocks there are brown earths with gleying. Surface soils of silt loam, suggesting aeolian deposits, rarely occur below 300 feet, but do occur in the highest parts of the area.

Soils on the valley floors are developed on either alluvium or river terraces. On alluvium the wide range of drainage conditions and calcium-carbonate content give five mapping units, including peaty soils, calcareous and non-calcareous gley soils and rendzina-like warp soils. On adjacent low terraces the thickness and texture of the material overlying the gravel are the most variable characteristics, but most soils are freely drained brown earths (sols lessivés).

The intervening steep slopes, where Chalk is the bedrock, have a

sequence of soils similar to that on the Chilterns, except that the Charity series is missing. (Jarvis.)

Gloucestershire and Wiltshire

Sheet 156, 7th Series (Bristol and Stroud)

About 240 sq. miles have now been surveyed, mainly on the Cotswolds except for a short stretch of the Avon valley between Chippenham and Melksham. The strongly dissected part of the Cotswolds around Stroud and Bath presents a regular association of soils. Very steep slopes on Fuller's Earth, frequently slumped and thickly wooded, give way to gentler slopes with brashy limestone soils carrying arable crops. A spring-line often marks the junction of the limestone or limestone Head and the underlying sandy or clay strata which give rise to a complicated pattern of light-textured soils of differing drainage supporting permanent grass and orchards.

In contrast with the scarp slopes, the higher dip-slope provides extensive stretches of gently sloping land with few shallow dry valleys. These are mainly covered by a thin, brashy clay loam, except in valley floors or where Fuller's Earth clay outcrops in thin bands on some valley sides.

East of a line Avening–Badminton–Corsham the pattern is complex, as the country is more undulating, more thickly wooded and has more extensive stretches of soils derived from Forest Marble clay. Although the surface soils may be sandy, because of variations in the parent rock or the presence of a coarse-textured drift, drainage is impeded by the underlying clay. Around Chavenage, Westonbirt and Gastard are small patches of well-drained, stoneless loamy soils. The area underlain by Cornbrash also provides a characteristic association of soils with extensive, nearly flat tracts of brashy soils of variable texture above which rise low, rounded clay hills. Although similar to those on the Great Oolite Limestone, the Cornbrash soils need artificial drainage.

Where the Oxford Clay outcrop is continuous, soils are not unlike those on Forest Marble clay, with loamy surface soils and impeded drainage. North of Chippenham, the Kellaways sands are thick, and deep light-textured soils predominate, though drainage is not everywhere free.

Wide gravelly terraces with well-drained loams occur on the west bank of the Avon, but on the east the gravels are thinner and the soils are poorly drained on the flat surface of the Oxford Clay. (Findlay.)

Devon

Work on the Nuffield Farm Project area in the Teign Valley was completed and an account prepared for local distribution with the map at 1 : 25,000 which is now ready for printing.

Reconnaissance survey was started on Sheet 176, 7th Series (Exeter), which includes the Project area, and a further 20 sq. miles were covered on the Haldon Hills and in the Bovey Basin. Great and Little Haldon form a narrow, flat-topped plateau at 700–800

feet extending in a N.–S. direction parallel with and midway between the Exe estuary and the middle reaches of the Teign. Coarse flint gravels with seams of granitic sand and whitish clay cover most of the plateau and overlie Greensand, the narrow outcrop of which around the edge of the plateau is frequently mantled by flinty Head. The soils on the gravels and the marginal Greensand are included in the Haldon association. They are mainly iron-humus podzols, but vary considerably owing to local differences in parent material. Most of Haldon is now planted by the Forestry Commission, but large areas remain of the former cover of semi-natural wet heath.

The Bovey Basin occupies a rectangle of low-lying, gently undulating ground, between Bovey Tracey and Newton Abbott, crossed by the lower course of the Teign. Oligocene clay, sand and lignite derived from Dartmoor underlie the Basin, but are mainly covered by Head of varied composition. Clay- and sand-pits are extensive, and extraction of "ball-clay", begun about 1740, still continues. Surface-water gley soils and peaty gley soils are extensive where dense whitish clay occurs close to the surface; podzols and sandy brown earths occur on marginal sands and gravels, with acid brown earths on more loamy Head. Ground-water gley soils of fine sandy loam texture were mapped on the flood plains of the Teign and Bovey. (Clayden and Manley.)

Sussex

Sheets 332 (Bognor) and 317 (Chichester)

About 25 sq. miles were mapped, extending the survey west towards the Hampshire border and about 1 mile up the slope of the South Downs. Several soils already mapped on the Chalk (Sheet 238, Aylesbury) were recognised, including Charity, Icknield, Coombe, Winchester and Wallop series. Three new mapping units were needed, one of which can probably be correlated with the Andover series, the shallow brown calcareous soil on the Hampshire Chalk. The Icknield (shallow phase) is mainly confined to the steeper slopes and crests of narrow ridges; elsewhere the Andover series predominates, except where Wallop and Winchester soils are formed on the Clay-with-flints capping broader ridge-tops above 400 feet. In the Chalk, Charity soils are confined to the lower slopes of valleys, often on terrace-like features, but southwards they expand to a broad belt where the Downs meet the coastal plain. As well as the normal Charity soils, very stony and shallow phases were mapped. (Hodgson.)

Kent

Reconnaissance mapping was started, and soils developed on or associated with the Chalk, Gault, Lower Greensand and Weald Clay were examined. In connection with a course on soils held at Juniper Hall, similar examinations were made around Dorking, Surrey, and about 20 sq. miles were mapped at 1 : 25,000.

The preparation of maps and the memoir dealing with Romney Marsh is proceeding. (Green.)

Other Work

1. Several surveyors took part in describing soils at the sites of field trials of different kinds.

2. A report was made for the Agricultural Land Service on the possibility of reclaiming Pilling–Cookerham Marsh. (Hall and Folland.)

3. The Hertfordshire Agricultural Institute Farm at St. Albans was surveyed. (Thomasson.)

4. At the request of the Department of Scientific and Industrial Research Hydraulics Research Station the 8 sq. miles of the Grendon Underwood Experimental Catchment were surveyed. Rainfall and stream-flow are being measured there, and seasonal changes in soil-moisture status are being measured by direct sampling, tensiometer and resistance-block methods at sites chosen on the basis of the soil survey. (Avery.)

5. The degree and rate of podzolisation under conifers of three soils in close proximity is being studied. (Ashley.)

6. A study of the colonisation by vegetation of bare sand and gravel surfaces suggests that colonisation is speeded by nitrogenous manures. (Crompton and Bullock.)

7. The morphology of soils developed on silty parent materials is often similar to that of podzols on sandy materials. Micromorphological studies, however, show that the B horizon has small well-flocculated aggregates of weakly birefringent clay more resembling those in the braunerde (Kubiëna) than those in the spodic horizon of American authors. (Mackney, Burnham and Waine.)

8. A small area considered suitable for a Nature Reserve in the Isle of Wight was surveyed. (Hodgson.)

9. At the request of the Forestry Commission a reconnaissance survey was made of part of Halwill Forest, Holsworthy, where problems occur on surface-water gley soils. (Clayden and Manley.)

10. The environs of a proposed reservoir near Pontypool were surveyed to advise on their suitability for wildfowl and conservation. (Crampton.)

MICROBIOLOGICAL OBSERVATIONS ON THE CLASSICAL FIELDS AT ROTHAMSTED

JANE MEIKLEJOHN

The Rothamsted field experiments offer great opportunities for the study of Soil Microbiology. Here, as nowhere else, the effects of long-continued treatments of the same soil on its population of micro-organisms can be observed. Perhaps the opportunities have not been fully exploited, but several fundamental discoveries of the true nature of the microscopic population of soils have been made, notably that Protozoa are true soil inhabitants, and that the total population must be reckoned in thousands of millions per gram of soil. (Much work has also been done on soil-borne plant pathogens in the Rothamsted fields, but this has been most ably reviewed by others (see, for instance, Glynne & Salt, 1957), and little would be gained by repeating what has been better done already.)

The earliest microbiological observations on Rothamsted soils were made by Robert Warington in 1883. In that year he took soil samples at different depths on Agdell field, which at that time carried a long-term experiment on two four-course rotations (turnips, barley, bare fallow, wheat; turnips, barley, clover, wheat) and found that surface soil, and soil down to but not below 18 inches, contained nitrifying bacteria. He repeated the work the next year, when he failed to find nitrifiers at a depth greater than 9 inches (Warington, 1884).

There was then a gap of more than twenty years before Ashby (1907) examined a series of soils collected at Rothamsted for the then recently discovered bacterium, *Azotobacter chroococcum*, which could fix nitrogen from the air. He found that it was abundant in the soil of Broadbalk Wilderness, and fairly abundant in the Drain Gauges. In Agdell it was present in the limed but not the unlimed plots, and it could not be found in three Park Grass plots (1, 4 and 9) or in Geescroft Wilderness (which has a more acid soil than the Broadbalk Wilderness).

Two years later, in 1909, appeared the first of a series of papers by Russell and Hutchinson on the effects of partial sterilisation of soil on crop growth and on the numbers of bacteria. Their first experiments were made with unmanured soil taken from the headland of Barnfield. They treated this soil with steam, and with toluene, and counted the bacteria by the plate method on nutrient gelatine. The count in the untreated soil was 5–9 million bacteria/g.; treatment with steam or toluene diminished the count to about half this value at first, but 10 days later the count had risen to 40 million bacteria/g. The same gelatine plate method showed bacterial numbers of 14–77 millions/g. in the dunged plot of Barnfield, but only 12 millions/g.

in Hoos Field unmanured plot (Russell and Hutchinson, 1909, 1913; Hutchinson, 1913). Partial sterilisation thus increased crop yields and bacterial numbers after a temporary fall; from these results Russell and Hutchinson concluded that there was some factor in soil which limited both bacterial growth and soil fertility, and which was removed by partial sterilisation. As they succeeded in growing the ciliate Protozoon *Colpoda* in hay infusion inoculated with soil, they thought that it must be the soil Protozoa that were the harmful factor. Goodey (1911) found several species of Protozoa, mostly ciliates but some amoebae, in fresh and in old stored soil samples taken from Barnfield and Hoosfield unmanured plots. Critics of his work suggested that the Protozoa were not true soil inhabitants, but were accidentally blown into the soil in their encysted stage, and remained encysted. Martin and Lewin (1915), however, discovered that Protozoa lived in the soil as active forms, mobile and able to feed, and not only as cysts. They examined samples taken from Broadbalk plots 2 and 3 (FYM and unmanured), and from Agdell fallow.

In 1917 Russell and Appleyard published counts made on gelatine plates of bacteria from soil samples collected during a whole year from Broadbalk plots 2 and 3 (and from Great Harpenden field). Numbers fluctuated on all the plots and their attempt to relate the fluctuations to the nitrate content of the samples (not surprisingly) failed. The fluctuations were not related to soil temperature or soil moisture, and Russell and Appleyard said that they might have been caused by the predatory activities of soil Protozoa. The carbon dioxide output of incubated soil samples was shown to be related to the numbers of bacteria in them, and the output of carbon dioxide has been used since by many workers as a convenient index of microbial activity in soils. This paper also includes one of the earliest estimations of the amount of nitrate lost from the soil in autumn by leaching and otherwise.

In 1920 Cutler published a method for counting total numbers of Protozoa, and also the numbers of active (i.e., not encysted) Protozoa in soil samples. This method, which depended on the development of Protozoa on peptone–meat-extract–agar plates inoculated with dilutions of a soil suspension, was used by Crump (1920) to study the soil Protozoa in plots 2 and 3 of Broadbalk, the dunged plot (1–0) of Barnfield and an unmanured plot on Great Harpenden. She found that the most numerous Protozoa were small flagellates, which varied in numbers from 1,000 to 100,000/g. of soil. Amoebae were fewer, from 100 to 50,000/g., and ciliates were not always present, and never more than 1,000/g. Very few Protozoa were found deeper than 6 inches below the soil surface. In surface samples there were more Protozoa in dunged plots than in unmanured plots. In all the plots the numbers fluctuated similarly, with peaks at the same time of year; the fluctuations could not be correlated with changes in soil temperature or moisture, or with rainfall, but there was some indication that they went in the opposite direction to changes in the plate count of bacteria.

This point was investigated further by Cutler and Crump (1920), who found that the numbers of active forms of three common soil flagellates (*Oicomonas*, *Cercomonas* and *Bodo* spp.) in the soil of

Broadbalk plot 2 fluctuated from day to day. Once again, these changes could not be related to soil moisture or temperature. In the same soil the numbers of active amoebae varied inversely with the plate counts of bacteria. A year later a really heroic experiment was undertaken by Cutler, Crump and Sandon (1922). They took a soil sample from the dunged plot (1–0) of Barnfield on every one of the 365 days from 5 July 1920 to 4 July 1921, and from these samples they obtained plate counts of bacteria on Thornton's agar (Thornton, 1922), and counted total and active Protozoa by Cutler's method. The results were examined in great detail, and showed that, on many occasions, the bacterial numbers were low when the Protozoa numbers were high, and vice versa. A common picture was to see a sudden rise in the bacterial count followed two or three days later by a rise in the numbers of one or other of the Protozoa. These results seemed at the time to indicate that the predatory action of the Protozoa was limiting the numbers of bacteria in soils; but subsequent work showed that knowledge of both the predators and the prey was far from complete. (See Thornton and Crump, 1952.)

It had become apparent for some time that the counts of bacteria obtained by plate methods were gross underestimates of the real soil population. No agar medium, however " unselective ", permits every bacterial species to develop, and it was obvious that anaerobic bacteria, and autotrophs, were not being included in the counts. Just how gross the underestimate was, however, came as a surprise to most bacteriologists. The plate counts, even on a better medium than the nutrient gelatine used by Russell and Hutchinson, estimated the bacterial population of a fertile soil at some tens of millions per gram. The first method of total counts, the ratio method of Thornton and Gray (1934), showed that the real bacterial population might be more than a hundred times as great. In this method a known small quantity of soil was mixed with a suspension of indigo containing a known number of indigo particles per ml., and drops of the mixture spread on microscope slides and stained with a red dye. The bacteria appeared as red dots and the indigo particles as blue dots, and comparing the numbers of each in random microscope fields gave an estimate of the soil population, of the order of thousands of millions per gram of soil. For instance, counts on Barnfield soil ranged from 1,900 to 2,900 millions/g. on different plots, and counts on Hoosfield from 1,700 millions on plot 1–0 (unmanured) up to 3,700 millions on plot 4-AA (nitrate of soda, phosphate and potash).

Another total counting method, the agar-film method of Jones and Mollison (1948), gives estimates of the same order of numbers. Counts done on Broadbalk by this method showed that Plot 2 (FYM) had the most bacteria and actinomycetes, and Plots 3 (unmanured) and 7 (ammonium sulphate and minerals) had similar numbers. The average count by the direct method was 2,500 million cells/g. of soil, and the average plate count 50 millions/g., $\frac{1}{50}$ of the direct count (Skinner, Jones and Mollison, 1952).

As well as the total numbers, several particular groups of microorganisms have been counted at Rothamsted. Algae were counted in samples from Broadbalk plots 2 and 3 by Bristol Roach (1927), who found the same species on both plots, but more numerous on the

dunged plot 2. J. Singh (1937) made plate counts of fungi and actinomycetes, on an agar medium, pH 5·2, that was not really favourable to either group. On both Broadbalk and Barnfield he found most in the plots with organic manures, and fewest in the unmanured plots. Skinner (1951) found that the high numbers of actinomycetes in Broadbalk plots 2, 3 and 7 were nearly all in the spore stage at the time of counting, with very little mycelium present.

Jensen (1931) used soil from two plots on Park Grass to study the decomposition of farmyard manure. In the limed soil from plot 1, pH 7, he found that the numbers of bacteria and actinomycetes were increased when the soil was incubated with farmyard manure and straw; but in the acid unlimed soil, pH 3·8, from plot 14, the same treatment increased only the numbers of fungi. From the soil of plot 1 he isolated a cellulose-decomposing bacterium, a species of Vibrio, which appeared to be the most numerous cellulose decomposer at pH 7. From the acid plot 14 he isolated cellulose decomposing fungi; and from Hoosfield soil, of intermediate acidity (pH 6·3), he obtained the Vibrio, and also the Myxobacterium *Sporocytophaga*, which had been discovered at Rothamsted by Hutchinson and Clayton in 1919 (Jensen, 1931b). From the Hoosfield soil Jensen also isolated two actinomycetes active in breaking down keratin (Jensen, 1930) and two species of fungi able to decompose chitin (Jensen, 1932).

In 1946 B. N. Singh described an improved method of counting Protozoa in soils. This was based on his discovery that the Protozoa were selective in their choice of food, eating some species of bacteria readily and others not at all. Small circles of an edible bacterium were spread inside glass rings embedded in plain agar, and inoculated with serial dilutions of the soil sample. As the Protozoa developed they ate the bacterial circle, and the different kinds were easy to detect in the small space. Singh (1949), by this method, counted amoebae in plots on Barnfield and Broadbalk. On both fields numbers were highest in the dunged plot and lowest in the unmanured, with a plot with sulphate of ammonia and minerals giving a count between the two (see Table 1).

TABLE 1

Numbers of amoebae per gram dry soil (Singh, 1949)

Barnfield (mean of 9 observations)

Unmanured (8–0)	FYM (1–0)	Ammonium sulphate and minerals	
8,000	34,000	26,000	(4 A)

Broadbalk (mean of 6 observations)

Unmanured (3)	FYM (2)	Ammonium sulphate and minerals	
17,000	72,000	48,000	(7)

Singh also discovered, by this same method, that several micropredators, once thought to be rare, were in fact widely distributed and numerous in soils. Some of these, the Acrasieae, for instance, were thought to live in dung only, and not to be true soil inhabitants. But Singh found that the Acrasian *Dictyostelium*, the gigantic amoeboid predator *Leptomyxa reticulata*, and the higher Myxobacteria *Myxococcus*, *Chondrococcus* and *Archangium*, were all pre-

sent and quite numerous in the soil of Broadbalk Plot 3, which has received no manure of any kind for more than a hundred years (Singh, 1947a, 1947b, 1948).

Some specialised groups of bacteria have also been counted in the Rothamsted classical fields. In the autumn of 1930 and 1931 Ziemięcka (1932) took a series of soil samples, and used Winogradsky's method of crumbs of soil on silica gel to count the nitrogen fixer *Azotobacter chroococcum*, and also the ammonia-oxidising bacteria in them. Her counts of Azotobacter, given in Table 2, show more in plots without added nitrogen.

TABLE 2

Azotobacter: cells per gram dry soil (Ziemięcka, 1932)

	Mean Nos. of Azotobacter
Unmanured (6 observations)	
Broadbalk 3, Hoosfield 1–0 and 7–1, Agdell 5 and 6 ...	852
P, K, *no* N (6 observations)	
Broadbalk 5, Hoosfield 4–0, Agdell 3 and 4, Barnfield 4–0	2,382
N: *Ammonium sulphate* (10 observations)	
Broadbalk 6, 7, 8, 10, 11, 12, 13, 14, Hoosfield 4–1 ...	231
N: *Sodium nitrate* (7 observations)	
Broadbalk 9 and 16, Hoosfield 3–AA and 4–AA, Barnfield 4–N	568
N: *Organic* (7 observations)	
Broadbalk 2 and 19, Hoosfield 3–0, 4–0 and 7–2	550
All plots without nitrogen (12 observations)	1,617
All plots with nitrogen (24 observations)	423

The ammonia oxidisers, by contrast, seemed to be most numerous in the plots with added organic nitrogen (farmyard manure or rape cake) (Table 3). Ammonia-oxidising bacteria have now been isolated from Broadbalk Plot 2, and identified as *Nitrosomonas europaea* Winogradsky (Meiklejohn, 1949).

TABLE 3

Ammonia oxidisers: cells per gram dry soil (Ziemięcka, 1932)

	Broadbalk	Barnfield
Unmanured	252	384
P, K, no N	406	334
Ammonium sulphate	1,949	252
Sodium nitrate	—	987
Rape cake	1,336	3,687
Farmyard manure	2,243	3,198

The results in these two tables are based on single observations. Recently I have counted *Azotobacter chroococcum* at intervals over a period of 3½ years in samples taken from eight plots on Broadbalk (Meiklejohn, 1962). The number of cells always fluctuated from sample to sample, but in spite of this there were real differences between plots. In general, the plots which showed the greatest increase in the yield of wheat after fallowing had the most Azotobacter. Plot 10, for instance, which receives sulphate of ammonia only (no P or K), and has an average increase in yield of 3 cwt. of grain/acre, has consistently fewer Azotobacter than Plot 5, receiving P and K but no N, which has an average yield increase of 9 cwt./acre

after fallow. Table 4 shows the average counts of Azotobacter for eight Broadbalk plots.

TABLE 4

Azotobacter: cells per gram dry soil (Meiklejohn, 1962)
(Broadbalk)

Plot	Treatment	Number of observations	Mean No. of Azotobacter
3	Unmanured	56	167
5	Minerals (P, K, no N)	49	178
7	Ammonium sulphate, P, K	50	107
10	Ammonium sulphate only	52	77
11	Ammonium sulphate, P	35	140
13	Ammonium sulphate, P, K	35	139
17 & 18	Alternate years: P, K, no N	50	220
17 & 18	Alternate years: Ammonium sulphate	50	199

Few Azotobacter were found, probably because of the medium used, which has since been found to underestimate the numbers of Azotobacter. The error, however, appears to affect all counts in the same proportion, so that, though the real numbers are all higher than those shown, plots 17 and 18, for instance, really have more Azotobacter than plot 10. And in any case, Azotobacter is not the only nitrogen fixer in the Broadbalk soil. It is not even the most numerous. A few counts made of the anaerobic nitrogen-fixing bacterium *Clostridium pasteurianum* show consistently higher numbers than those of Azotobacter. In all the eight plots sampled, nitrogen-fixing Clostridia were found to amount to 100,000 g. or more on at least one occasion, and very few counts numbered fewer than 1,000 cells g. of soil. There were not enough data for any differences between plots to be detected (Meiklejohn, 1956).

It is obvious, I think, that much remains to be done before the Rothamsted classical fields can be said to be adequately studied. The work already done has disclosed that the population of micro-organisms in cultivated soils must be numbered in thousands of millions per gram, and has given some indication of the complexity of this population. Future advances in useful knowledge are, however, more likely to be made not by attempting to study the " whole " soil population, but by more detailed study of the groups of micro-organisms responsible for particular processes important to soil fertility. The best line of approach is indicated by the work of Jensen. In his study of the decomposition of manure he was able to use two soils, from Park Grass plots 1 and 14, that had been changed by fertiliser treatment so that one was neutral and the other very acid, and so to find out that soils of different acidity contain different groups of cellulose decomposers. Further studies of this kind on the classical fields, where the soil properties are so well known, and all the yields are recorded, would take some useful advantage of the unique opportunities offered by the Rothamsted classical fields.

REFERENCES

ASHBY, S. F. (1907). Some observations on the assimilation of atmospheric nitrogen by a free living soil organism—*Azotobacter chroococcum* of Beijerinck. *J. agric. Sci.* **2**, 35–51.

Bristol Roach, B. M. (1927). On the Algae of some normal English soils. *J. agric. Sci.* **17**, 563–588.

Crump, L. M. (1920). Numbers of Protozoa in certain Rothamsted soils. *J. agric. Sci.* **10**, 182–198.

Cutler, D. W. (1920). A method for estimating the number of active Protozoa in the soil. *J. agric. Sci.* **10**, 135–143.

Cutler, D. W. & Crump, L. M. (1920). Daily periodicity in the numbers of active soil flagellates; with a brief note on the relation of trophic amoebae and bacterial numbers. *Ann. appl. Biol.* **7**, 11–24.

Cutler, D. W., Crump, L. M. & Sandon, H. (1922). A quantitative investigation of the bacterial and protozoan population of the soil, with an account of the protozoan fauna. *Phil. Trans. B.* **211**, 317–350.

Glynne, M. D. & Salt, G. A. (1957). Eyespot of wheat and barley. *Rep. Rothamst. exp. Sta.*, pp. 231–241.

Goodey, T. (1911). A contribution to our knowledge of the Protozoa of the soil. *Proc. roy. Soc. B.* **84**, 165–180.

Hutchinson, H. B. (1913). The partial sterilisation of the soil by means of caustic lime. *J. agric. Sci.* **5**, 320–330.

Hutchinson, H. B. & Clayton, J. (1919). On the decomposition of cellulose by an aerobic organism (*Spirochaeta cytophaga*, n.sp.). *J. agric. Sci.* **9**, 143–173.

Jensen, H. L. (1930). Decomposition of keratin by soil micro-organisms. *J. agric. Sci.* **20**, 390–398.

Jensen, H. L. (1931) a. The microbiology of farmyard manure decomposition in soil. **1.** Changes in the microflora, and their relation to nitrification. *J. agric. Sci.* **21**, 38–80.

Jensen, H. L. (1931) b. The microbiology of farmyard manure decomposition in soil. **2.** Decomposition of cellulose. *J. agric. Sci.* **21**, 81–100.

Jensen, H. L. (1932). The microbiology of farmyard manure decomposition in soil. **3.** Decomposition of the cells of micro-organisms. *J. agric. Sci.* **22**, 1–25.

Jones, P. C. T. & Mollison, J. E. (1948). A technique for the quantitative estimation of soil micro-organisms. *J. gen. Microbiol.* **2**, 54–69.

Martin, C. H. & Lewin, K. R. (1915). Notes on some methods for the estimation of soil Protozoa. *J. agric. Sci.* **7**, 106–119.

Meiklejohn, J. (1949). Isolation of *Nitrosomonas* from Rothamsted soil. *Nature, Lond.* **164**, 667.

Meiklejohn, J. (1956). Preliminary notes on numbers of nitrogen fixers on Broadbalk field. *Proc. 6th int. Congr. Soil Sci., Paris, C*, 243–248.

Meiklejohn J. (1962). Counts of *Azotobacter* on Broadbalk field. (Unpublished.)

Russell, E. J. & Appleyard, A. (1917). The influence of soil conditions on the decomposition of organic matter in the soil. *J. agric. Sci.* **8**, 385–417.

Russell, E. J. & Hutchinson, H. B. (1909). The effect of partial sterilisation on the production of plant food. *J. agric. Sci.* **3**, 111–144.

Russell, E. J. & Hutchinson, H. B. (1913). The limitation of bacterial numbers in normal soils and its consequences. *J. agric. Sci.* **5**, 152–221.

Singh, B. N. (1946). A method of estimating the numbers of soil Protozoa, especially amoebae, based on their differential feeding on bateria. *Ann. appl. Biol.* **33**, 112–119.

Singh, B. N. (1947) a. Myxobacteria in soils and composts; their distribution, number and lytic action on bacteria. *J. gen. Microbiol.* **1**, 1–10.

Singh, B. N. (1947) b. Studies on soil Acrasieae. I. Distribution of species of *Dictyostelium* in soils of Great Britain, and the effect of bacteria on their development. *J. gen. Microbiol.* **1**, 11–21.

Singh, B. N. (1948). Studies on giant amoeboid organisms. I. The distribution of *Leptomyxa reticulata* Goodey in soils of Great Britain, and the effect of bacterial food on growth and cyst formation. *J. gen. Microbiol.* **2**, 8–14.

Singh, B. N. (1949). The effect of artificial fertilisers and dung on the numbers of amoebae in Rothamsted soils. *J. gen. Microbiol.* **3**, 204–210.

Singh, J. (1937). Soil fungi and Actinomycetes in relation to manurial treatment, season and crop. *Ann. appl. Biol.* **24**, 154–168.

Skinner, F. A., Jones, P. C. T. & Mollison, J. E. (1952). A comparison of a direct- and a plate-counting technique for the quantitative estimation of soil micro-organisms. *J. gen. Microbiol.* **6**, 261–271.

Thornton, H. G. (1922). On the development of a standardised agar medium for counting soil bacteria, with especial regard to the repression of spreading colonies. *Ann. appl. Biol.* **9**, 241–247.

Thornton, H. G. & Crump, L. M. (1952). Micro-predators in soil. *Rep. Rothamsted exp. Sta.*, pp. 164–172.

Thornton, H. G. & Gray, P. H. H. (1934). The numbers of bacterial cells in field soils, as estimated by the ratio method. *Proc. roy. Soc. B.* **115**, 522–543.

Warington, R. (1884). On nitrification. (Part III.) *J. chem. Soc.* **45**, 637–672.

Ziemięcka, J. (1932). The *Azotobacter* test of soil fertility applied to the classical fields at Rothamsted. *J. agric. Sci.* **22**, 797–810.

BARNFIELD

R. G. Warren and A. E. Johnston

Lawes and Gilbert started a manurial experiment on mangolds on Barnfield in 1876, the same year they began to study the manuring of potatoes on what is now the Exhaustion Land. Except for a few years when the crops failed, mangolds have been grown on Barnfield each year from 1876 to 1959. From 1946 to 1959 a part of each plot, the same part each year, was sown with sugar beet. The results up to 1894 were summarised by Lawes and Gilbert[1] in 1895, and in 1902 Hall[2] discussed the results in detail. The next account of the experiment was by Watson and Russell[3,4,5,6,7] in five papers examining the results up to 1940. Our account gives results since 1940, and in addition to the mean yields for mangolds from 1941 to 1959 and sugar beet from 1946 to 1959, chemical analyses are given of crop and soil samples taken in 1958 and 1959.

At the time the experiment began mangolds were widely grown. Knowledge on its culture and manuring was derived from the experience of farmers and from field experiments. Salt gave good increases in yield, and fertilisers such as sodium nitrate and potassium nitrate were especially effective. The effect of phosphates on mangolds was small. Lawes and Gilbert's chief object in studying mangolds was to extend the range of crops in their investigations on the sources from which plants obtained nitrogen. They had already destroyed the belief that the large leaves of turnips, swedes and sugar beet could absorb enough ammonia from the air to meet their requirements. Even the application of a "starter" dose of nitrogen (about 8 lb. N/acre as ammonium salts) given to increase leaf area in the early stages of the plant's growth did not succeed.

The Mangold Experiment followed experiments with swedes and sugar beet on the same site, and the manuring was mainly a continuation of the schemes of these earlier experiments. There were eight long strips of land, side by side, each about $\frac{9}{10}$ acre, which were given the following treatments: (1) FYM; (2) FYM, P—from 1895 K also given; (3) unmanured—discarded in 1903 because it was very narrow; (4) P, K, Na, Mg; (5) P; (6) P, K; (7) N, P, K—the N was a small dose, about 8 lb. N/acre—from 1903 this strip received P, Na, Mg; (8) unmanured. This scheme did not provide a satisfactory test of P, as no strip received K only. Because Mg was always accompanied by Na there was no test of Mg, and the strip comparison of Na and K was also affected. Across the Strip treatments there were five Series treatments, no nitrogen (O), sodium nitrate (N), ammonium sulphate (A), ammonium sulphate and rape cake (AC) and rape cake (C). In 1941 rape cake was unobtainable, and in that year and since castor bean meal was used. After Strip 3 (unmanured) was discarded the Strip and Series scheme contained thirty-five main plots, one per treatment. In the layout in the field there was a gap, not under experiment, between Series O

TABLE 1

Crops and manures, Barnfield, 1843–1959

Period	Crop	Strip treatments 1								Series treatments [1]
		1	2	3	4	5	6	7	8	
1843–44	Turnips	See note [2]								None
1845–48	Turnips	P [3]	P	None	P, K, Na, Mg	P	PK	PK	P	O [4] A AC C
1849–52	Swedes	P [3]	P	None	P, K, Na, Mg	P	PK	PK	P	O [4] A AC C
1853–55	Barley	Manures not applied in these years [5]								
1856–60	Swedes	FYM	FYM, P	None	P, K, Na, Mg	P	PK	PK [6]	None	O N A AC C
1861–70	Swedes	FYM	FYM, P	None	P	P	P	P	None	O N A AC C
1871–75	Sugar beet	FYM	FYM, P	None	P, K, Na, Mg	P	PK	PK [6]	None	O N A AC C
1876–1902 [7]	Mangolds	FYM	FYM, P [8]	None [9]	P, K, Na, Mg	P	PK	PK [6]	None	O N A AC C
1903–59	Mangolds [10]	FYM	FYM, P, K		P, K, Na, Mg [11]	P	PK	PNaMg	None	O N A AC C

(1) Nitrogen cross dressings, O, none; A, ammonium salts; C, 1856–60 sawdust, 1861–1939 rape cake, 1940–59 castor bean meal; AC, treatments A and C combined; N, 1856–60 sawdust and nitric acid containing as much nitrogen as applied in Series A; 1861–1959 sodium nitrate.

(2) In 1843–44 there were 24 strips to which various manures were applied including FYM, guanos and combinations of N, P, K, Na, Mg. See *J. R. agric. Soc.* 1847, **8**, 494. These were later combined to make 8 strips.

(3) Parts of the plot received rape cake and farmyard manure.

(4) In " The Valley " between the O and A Series a number of manures, including phosphates and guanos, were applied. Subsequently Series N occupied part of this valley.

(5) In 1854 400 lb ammonium salts were applied to the valley sections of Strips 4, 5, 6, 7 to evaluate nitrogen residues on main plots.

(6) 36·5 lb. ammonium salts also applied. These contained 7·8 lb. N equal to the amount of nitrogen applied in the sawdust on Series N.

(7) An additional plot (9) which was not part of the main scheme of Strip and Series manuring was started in 1876 on the triangular piece of land on the East side of the experimental area. This plot received per acre in 1876–1902, FYM 14 tons, superphosphate, 350 lb. till 1887, 392 lb. 1888–1902; 400 lb. ammonium salts; 1903–1959, 500 lb. potassium sulphate, 200 lb. sodium chloride, 200 lb. magnesium sulphate, 550 lb. sodium nitrate.

(8) FYM, P changed to FYM, PK in 1895.

(9) Strip 3 was very narrow and yields have not been recorded since 1902 (manured and cropped as " commercial " since 1927).

(10) From 1946 4 rows sugar beet replaced 4 rows mangolds on each plot, the same part each year.

(11) From 1903 plot 4N split 4Na (west) was manured as the rest of the strip, 4Nb received no sodium but nitrate as mixed KNO_3 $CaNO_3$ and $CaCl_2$ to balance chloride in the sodium chloride on 4Na.

TABLE 2

Details of Strip and Series treatments, Barnfield, 1845–1959

Treatment symbol	FYM	P	K	Na	Mg	Series A	Series N	Series C	Series AC
	Amounts of manures [14] per acre, annual application								
Period	Farmyard manure (tons)	Super-phosphate (lb.)	Potassium sulphate (lb.)	Sodium chloride (lb.)	Magnesium sulphate (lb.)	Ammonium salts [1] (lb.)	Sodium nitrate [2] (lb.)	Rape cake [2]	Ammonium salts (A) + rape cake (C)
1845–52		275 [4]	334 [5]	88 [6]	75	200 [7]		2000 [7]	A + C [7]
1856–60	14	350	300	200 [8]	100	200	See Note 2	See Note 3	A + C [8]
1861–70	14	350				400	550	2000	A + C
1871–75	14 [9]	350	460	200	180	400 [9]	550 [9]	2000 [9]	A + C [9]
1876–1902	14	350	500	200	200	400	550	2000	A + C
1903–59 [13]	14	392 [10] 392	500 [11]	200	200 [11]	400 [12] 420 [15]	550 [12]	2000	A + C

(1) Applied as equal weights ammonium sulphate and ammonium chloride to 1916 (except 1887, ammonium sulphate only), from 1917 all as ammonium sulphate.

(2) 1856–60 3,000 lb. sawdust + nitric acid containing as much nitrogen as applied in Series A.

(3) 1856–60 3,000 lb. sawdust replaced rape cake, 1861–1939 rape cake (not applied 1917–20), 1940–59, castor bean meal, 1955 and since weight acre adjusted from analysis so that total nitrogen applied equalled 86 lb./acre.

(4) Strip 4 370 lb.; Strip 5 345 lb.; Strip 8 in 1842–52 was divided lengthwise into 3 equal strips, the total application of superphosphate to each strip was west strip 1,000 lb., central strip 4,800 lb., east strip 500 lb.

(5) Applied as pearl ash, strip 4 received only 228 lb.

(6) As soda ash.

(7) No nitrogen in 1851, 1852.

(8) As sodium sulphate.

(9) No FYM or nitrogen cross dressings in 1874, 1875.

(10) 350 lb. to 1887, from 1888 392 lb. of superphosphate supplied to the Farm already made, probably Works made. 1896–1902 superphosphate replaced by 400 lb. basic slag.

(11) K, Mg omitted 1917, 1918.

(12) No nitrogen applied 1874, 1875, 1884, 1901, 1903.

(13) To correct acidity that had developed on Series A and AC ground chalk (5 tons/acre) was applied in spring 1956. To prevent further acidity developing a scheme of quinquennial chalk applications was introduced, the amount being based on the acidifying effect of the ammonium sulphate and rape cake (Series A 31·6, AC 47·4, C 15·8 cwt. $CaCO_3$/acre).

(14) Nitrogen: 86 lb. N acre in 400 lb. ammonium salts, 420 lb. ammonium sulphate, 550 lb. sodium nitrate; 98 lb. N acre was assumed to be supplied by 2,000 lb. rape cake; castor bean meal from 1955 supplied 86 lb. N.

Phosphorus: 1845–58 21 lb. P supplied by 275 lb. superphosphate, from 1856 29–30 lb. P supplied each year.

Potassium: 40·7% K in potassium sulphate, 45% K in pearl ash.*

Sodium: 39·3% Na in sodium chloride, 34% Na in soda ash.*

Magnesium: 10·0% Mg in magnesium sulphate.

* *J. R. agric. Soc.* 1852, **13**, 449.

(15) Cultivation and application of manures: 1871–1939 mangold leaves ploughed in in autumn, land reploughed in spring, harrowed, the land bouted 1844–1939 two bouts split back. From 1940 land ploughed in autumn only. To 1875 the seed was dibbled in, then drilled 26 inches between rows on ridge till 1939, on the flat from 1940. On plot 9, 1876–1902, the seed was drilled on the flat row 22 inches apart from 1876 as the remainder of the experiment. Lawes and Gilbert loosened 2 inches of the subsoil between 6 and 8 inches on several occasions by running a plough without mouldboard along the furrow bottom. In the winter of 1939–40 steam tackle was used to move a cultivator working at 12–15 inches through the soil and this brought some subsoil to the surface.

N: Till 1895 the N fertilisers were sown at the same time as the minerals (except 1892 when half was applied as a top dressing). 1896–1912 applied as a top dressing, by hand, between the rows. From 1913 one-third applied to the seedbed, remainder as a top dressing.

P: 1845–81 superphosphate drilled along each planting ridge. From 1882 broadcast with the K, Na, Mg.

K Na Mg fertilisers and rape cake applied in the spring and worked into the seedbed.

FYM: 1845–87 put on the flat in spring prior to bouting, 1888–1929 put between the bouts after the first bouting then covered in by the second bouting. 1930–59 applied just before autumn ploughing.

and Series X because of a depression in the land, known as " the valley ".

Before proceeding to discuss the results of the experiment, some features in the history of the site before the experiment need mention (fuller details of this period and of the period of the experiment are in Tables 1 and 2). Although the Mangold Experiment began in 1876, many of the plots had received the same treatment since 1861; some had received the same manures since 1845, though the amounts had often varied. Series O, A, AC and C (no nitrogen, ammonium sulphate and rape cake with and without ammonium sulphate) were started in the turnip experiment 1845, but Series N (sodium nitrate) came later in the swede experiment 1856–70. To make room for Series N, Lawes and Gilbert shortened the total width of Series A, AC and C and took in land at the upper part of the south slope of " the valley ". Before this the whole of " the valley " was used for experiments in which various manures, e.g., guano and phosphates, were applied. There is indeed a record in one of Lawes' notebooks of one material used that may have been the forerunner of ammoniated superphosphate; it was superphosphate " partially neutralised " with gas liquor. Parts of Strip 8 (unmanured) received phosphate in 1843–52. The effects on the chemical analyses of the soil of some of the treatments given before the Mangold Experiment began were still detectable in soil samples taken from the field in 1958.

Yields of Mangolds

Watson and Russell gave the mean yields of mangolds for two periods of the experiment, 1876–94 and 1904–40, because there were treatment changes in 1903 but none in each of the periods selected. Table 3 gives their figures and those for the last period, 1941–59. The outstanding feature of the table is the decrease in the yields of nearly all plots in the last period compared with either the first or second period. Except for the yields of the plots on Strips 2 and 7, where changes were made in 1903 in the mineral manuring, there was good agreement between the two earlier periods, and the only consistent differences were small (1–2 tons roots acre less in the second period). These differences occurred where no K, Na or farmyard manure was supplied, and they therefore probably reflect the exhaustion of soil potassium. Although the dressing of rape cake supplied about 30 lb. K acre, this was not enough to prevent a similar decrease in the second period on those rape-cake plots that received no fertiliser K, Na or farmyard manure. The differences between the yields of the second and third period were much greater. The yields of roots of the plots which received only inorganic fertiliser were 4–6 tons/acre lower in the last period, even where N, P, K; N, P, Na; and N, P, K, Na were applied, and on the farmyard manure plots they were 8 tons roots acre lower. No loss of yield occurred with rape cake, alone or with ammonium sulphate only, but at the higher levels of yield obtained when P, K; P, Na; or P, K, Na fertilisers were added with the rape cake, the decreases for the third period were similar to those for the plots which received inorganic fertilisers only.

TABLE 3

Mangolds, Barnfield: mean yield of roots (tons/acre)

Series:	O			A			N			C			AC		
	No nitrogen			Ammonium sulphate			Sodium nitrate			Rape cake			Rape cake + Ammonium sulphate		
Strip	1876–94	1904–40	1941–59	1876–94	1904–40	1941–59	1876–94	1904–40	1941–59	1876–94	1904–40	1941–59	1876–94	1904–40	1941–59
8 No P or K	3·8	3·0	1·5	6·0	5·6	5·8	10·2	10·6	8·1	10·2	8·3	8·4	10·1	7·5	8·1
5 P	5·0	4·0	2·2	8·3	6·8	7·4	15·7	16·1	11·7	12·0	9·4	9·8	11·2	8·8	9·3
6 P, K	4·5	3·8	2·1	13·7	14·5	11·7	15·5	16·8	12·3	18·0	17·6	14·4	22·1	22·0	18·9
7 P, Na, Mg [1] ...	(5·9)	4·0	2·2	(15·0)	16·1	12·2	(15·9)	18·4	12·4	(18·9)	19·2	15·1	(22·0)	21·5	17·0
4 P, K, Na, Mg ...	5·3	4·2	2·7	15·5	15·5	12·8	18·3	19·0	14·4	20·7	20·7	15·8	25·0	26·4	19·1
1 FYM	16·8	17·4	8·9	22·1	22·0	18·1	23·2	28·0	20·0	23·6	23·0	17·9	24·5	23·2	19·9
2 FYM, P, K * ...	(17·0)	19·9	11·3	(21·4)	26·9	19·6	(24·2)	29·4	21·7	(23·3)	27·8	20·7	(23·5)	29·4	23·5

* The figures in brackets are means for the period, but the treatments differed from that given later. See Table 1 (notes 6 and 8).

The lower yields in the last period of the experiment were mainly because responses to P, K and Na fertilisers, and to farmyard manure, were much smaller. Farmyard manure decreased the responses to PK fertilisers (N fertilisers present) by nearly the same amount in the second and third periods, $5\frac{1}{2}$ tons 1904–40 and 5 tons 1941–59. This suggests that the activity of the PK nutrients in farmyard manure remained constant, while the activity of the same nutrients in the form of fertilisers was considerably less in the last period. The response to N, however, was not less, indeed on the farmyard manure strip (Strip 1) it was greater in 1941–59. Tables 4 and 5 show the effects of the nutrients added as fertilisers on yield for the periods when comparison is possible.

TABLE 4

Increase of yield of roots by N *fertilisers in the absence of farmyard manure*
(*Barnfield—tons/acre*)

86 lb. N/acre applied as		Minerals		
	P, K	P, Na, Mg	P, K, Na, Mg
Ammonium sulphate			
1876–94	9·2	—	10·2
1904–40	10·8	12·2	11·3
1941–59	9·6	10·0	10·1
Sodium nitrate			
1876–94	11·1	—	13·0
1904–40	13·1	14·5	14·8
1941–59	10·2	10·2	11·7

TABLE 5

Increase of yield of roots by K, Na *and* Mg *in absence of farmyard manure*
(*Barnfield—tons/acre*)

		N applied, lb./acre			
		86	86	98	184
		Sodium nitrate	Ammonium sulphate	Rape cake	Rape cake + ammonium sulphate
K	1876–94	−0·2	5·4	6·0	11·0
	1904–40	0·8	7·7	8·1	13·2
	1941–59	0·6	4·3	4·6	9·6
Na + Mg ...	1904–40	2·4	9·3	10·9	12·7
	1941–59	0·7	4·8	5·3	7·7
K, Na + Mg	1876–94	2·6	7·2	8·7	13·9
	1904–40	2·9	8·7	11·2	17·6
	1941–59	2·7	5·4	6·0	9·8

Tables 6 and 7 compare the effects of N and PK fertilisers with and without farmyard manure.

The total effect of farmyard manure was much less in the last period (Table 8). Applied alone or with PK fertilisers, it increased yield by only half as much as in the preceding period, a fall in response of 7 tons roots/acre. Applied with N fertilisers, the mean effect of farmyard manure was increased by 4 tons in the third period, compared with 1·5 tons in the second period. Because in the third period the response to farmyard manure fell by more than

TABLE 6

Increase of yield of roots by N *fertilisers alone and in presence of farmyard manure and* PK *fertilisers*
(Barnfield—tons/acre)

Effect of	In presence of O		In presence of PK		In presence of FYM		In presence of FYM + PK	
	1904–40	1941–59	1904–40	1941–59	1904–40	1941–59	1904–40	1941–59
Ammonium sulphate	2·6	4·3	10·8	9·6	4·6	9·2	8·0	8·3
Sodium nitrate ...	7·6	6·6	13·1	10·2	10·6	11·1	9·4	10·4
Rape cake	5·3	6·9	13·8	12·3	5·6	9·0	7·8	9·4
Rape cake and ammonium sulphate ...	4·5	6·6	18·2	16·8	5·8	11·0	9·5	12·2

TABLE 7

Increase in yield of roots by PK *fertilisers alone and in presence of farmyard manure*
(Barnfield—tons/acre)

	Ammonium sulphate	Sodium nitrate	Rape cake	Rape cake + ammonium sulphate
1904–40				
No FYM	8·9	6·3	9·3	14·5
FYM	4·9	1·4	4·8	6·2
Difference	4·0	4·9	4·5	8·3
1941–59				
No FYM	5·9	4·2	6·0	10·8
FYM	0·5	1·7	2·8	3·6
Difference	5·4	2·5	3·2	7·2

TABLE 8

Increase of yield of roots by farmyard manure in absence and presence of other fertilisers
(Barnfield—tons/acre)

		N Fertilisers: O	Ammonium sulphate 86 lb. N	Sodium nitrate 86 lb. N	Rape cake 98 lb. N	Rape cake + ammonium sulphate 184 lb. N
No minerals	1904–40	14·4	16·4	17·4	14·7	15·7
	1941–59	7·4	12·3	11·9	9·9	11·8
PK ...	1904–40	16·2	12·4	12·5	10·2	7·4
	1941–59	9·2	7·9	9·4	6·3	4·6

did the response to K or Na, there was a change in the relation between the yields with farmyard manure and with fertilisers. Without rape cake in the first and second periods, farmyard manure gave 1 ton roots/acre more than PK fertilisers when the N fertiliser was ammonium sulphate (86 lb. N/acre), but 1 ton less when it was sodium nitrate. In the last period both forms of N (with PK) gave better yields than farmyard manure. The extra yields were:

Ammonium sulphate + PK . . . 2·8 tons roots/acre
Sodium nitrate + PK . . . . 3·4 tons roots/acre

Other than the differences mentioned, the general conclusions about the effects of fertilisers, rape cake and farmyard manure on the yields of mangolds in the Barnfield experiment are substantially the same for the three periods (Table 3). In addition to the main Strip and Series scheme, there were two other treatments, one on plot 9 and the other on half of plot 4N (see footnotes 7 and 11, Table 1). Plot 9, where the treatment was changed in 1903 to provide a test of P in the presence of K, Na, Mg, does not give a valid measure of the P response because of residues from the treatment during 1876–1902. Plot 4Nb has received no sodium since 1903 (for full treatments on plots 4Na and 4Nb see Table 1). As mean yields on 4Na and 4Nb are similar, sodium as such seems inessential with the existing manurial treatments.

Kalamkar[8] examined the variations in yield from 1876 to 1930, and separated the variations into three kinds: (1) steady diminution of yield, ascribable to soil deterioration; (2) other slow changes, ascribable to factors that vary regularly from year to year; (3) the residual variation, called the annual variation, ascribable to factors which vary irregularly from year to year, including seasonal weather conditions, experimental errors, etc.

Deterioration and slow changes accounted for only very small fractions of the total variation. Since then, however, response to K, Na fertilisers and to farmyard manure has become much smaller. The composition of farmyard manure may fluctuate from year to year, but longer-period changes are also possible, for example, from 1939 to 1946, when concentrates for feeding animals were scarce. The behaviour of N fertilisers in the presence and absence of farmyard manure for the two periods 1904–40 and 1941–59 (Table 6) indicates that the composition of the manure may have changed. The variations in responses to N fertilisers are best determined by comparing yields in the presence of PK fertilisers and of farmyard manure alone, not FYM + PK, as FYM itself supplies much P and K. During 1904–40 the responses to N fertilisers (omitting $NaNO_3$, because it provides an additional nutrient, Na) were 10·8–18·2 tons/acre in the presence of PK fertilisers but only 4·6–5·8 tons when farmyard manure was present, a loss which can be attributed to the effect of the N in the farmyard manure. In the third period farmyard manure had very little effect on the responses to the N fertilisers except at the very high level of N (184 lb. N/acre in rape cake + ammonium sulphate). These results indicate that the farmyard manure in the third period contained less available N on average than in the preceding period, and this is why response to farmyard manure was smaller. Table 6 also shows that even the " richer " farmyard manures in the second period had little effect on the responses to N fertilisers, provided that extra PK was supplied. In previous accounts of the Barnfield Experiment the figures for the composition of farmyard manure were average values from the Rothamsted Farm. Table 9 contains the average contents of total N, P and K in 14 tons of farmyard manure at different times in the history of the field.

Since 1941, the farmyard manures contained less nitrogen than previously, confirming the deduction already made about those used between 1941 and 1959. The amounts of P and K also changed,

TABLE 9

Composition of farmyard manures at Rothamsted

	N	P	K
	lb./14 tons of manure		
1850–60	200	35	140
1860–80	200	35	195
1900–10	200	35	85
1930–40	200	45	205
1941–50	170	40	160
1951–59	160	25	140

but these changes were not reflected in the influence of farmyard manure on the effects of PK fertilisers. This could be expected, because the PK residues from earlier applications of richer manures would remain active for a longer period than residues of organic nitrogen. Mineral nitrogen is produced slowly from old organic residues. A further factor, recorded in Table 2, Note 15, may have contributed to the lower effectiveness of farmyard manure in the last period of the experiment. Up to 1929 the farmyard manure was applied in March–April, but since then it has been ploughed in during late autumn or early winter. Comparisons of winter and spring applications of farmyard manure in other experiments at Rothamsted show a small gain of about 1 ton of potatoes/acre in favour of the spring applications.

The yields from Barnfield, however, provide no clue to the reason or reasons for responses to K and Na fertiliser also becoming less. The grades of the potassium sulphate and sodium chloride were not lower at the end of the experiment; nor was the time of application changed.

YIELDS OF SUGAR BEET

Four rows of sugar beet were grown on each plot of the Mangold Experiment during the last 14 years, except 1948 and 1956, when crops failed. For mangolds the ratio of tops to roots is small ($\frac{1}{4}$–$\frac{1}{6}$) but the ratio is much larger for sugar beet (1), and in Table 10, therefore, the mean yields for tops and for roots of sugar beet are given. In this set of results no comparison is possible between sodium nitrate and ammonium sulphate in the presence of the full

TABLE 10

Sugar beet, Barnfield: Mean yields, tons/acre, 1946–59

Series:	0		A		N		C		AC	
			Ammonium sulphate		Sodium nitrate				Rape cake + ammonium sulphate	
Strip	No Nitrogen Tops	Roots	Tops	Roots	Tops	Roots	Rape cake Tops	Roots	Tops	Roots
8 No P or K ...	2·0	1·5	4·9	4·2	6·1	5·0	7·5	5·6	9·0	6·4
5 P	2·1	1·9	4·8	5·0	7·4	6·7	6·6	6·9	9·3	7·2
6 PK	1·9	1·6	5·3	6·6	6·6	6·2	6·8	8·2	10·4	9·5
7 P Na Mg ...	2·1	1·8	6·4	7·2	7·8	7·2	8·4	7·7	11·7	9·0
4 P K Na Mg	2·0	1·8	5·8	7·2	7·5	8·0 *	7·5	9·1	10·2	10·3
1 FYM ...	5·2	6·2	12·2	11·5	10·6	11·1	10·3	11·4	12·1	11·4
2 FYM P K ...	5·5	5·9	9·0	8·6	11·0	9·9	9·8	9·8	11·2	10·3

* Sodium nitrate replaced by a mixture of potassium and calcium nitrates.

complement of minerals (P, K, Na, Mg) because the manuring of the half plot of 4N, on part of which the sugar beet was grown, was

changed in 1903. Sodium was replaced by calcium, and the nitrogen was applied as calcium and potassium nitrates.

The general pattern of the effects of the manurial treatments on the yields of sugar beet was similar to the pattern for the mangolds in the third period. For sugar-beet roots ammonium and nitrate nitrogen at an equal rate of N (86 lb./acre) gave the same increase, 5 tons/acre, in the presence of PK or P, Na fertilisers. Higher levels of N gave greater increases. Potassium, as potassium sulphate, and sodium, as sodium chloride, each increased the yield by 2 tons/acre where ammonium sulphate was used, but neither fertiliser had an effect when the nitrogen was supplied as sodium nitrate. NPK fertilisers containing 86 lb. N/acre as ammonium or nitrate gave 1–2 tons more roots per acre than farmyard manure.

The yields of sugar beet from the treatment farmyard manure + PK fertilisers show a new feature for Barnfield. Where N fertilisers and farmyard manure were applied, adding PK fertilisers decreased (1–3 tons) the yield of sugar beet but not of mangolds. Table 11 gives the effects of PK fertilisers in the presence and absence of farmyard manure for sugar beet and mangolds (third period). Effects on plots which received sodium nitrate are omitted for the reason stated when discussing Table 6.

TABLE 11

Effect of PK *fertilisers, Barnfield: Roots tons/acre*

Effect of PK	In presence of: Ammonium sulphate	Rape cake	Rape cake + ammonium sulphate
		Sugar beet 1946–59	
No FYM	2·4	2·6	3·1
FYM	−2·9	−1·6	−1·1
		Mangolds 1941–59	
No FYM	5·9	6·0	10·8
FYM	1·5	2·8	3·6

TABLE 12

Increase of yield of sugar beet and mangolds by N *fertilisers in the presence and absence of farmyard manure and* PK *fertilisers*

Barnfield (roots tons/acre)

Effect of	In presence of: PK		FYM		PK + FYM	
	Mangolds	Sugar beet	Mangolds	Sugar beet	Mangolds	Sugar beet
Ammonium sulphate	9·6	5·0	9·2	5·2	8·3	2·7
Rape cake	12·3	6·5	9·0	5·2	9·4	3·9
Rape cake + ammonium sulphate ...	16·8	7·9	11·0	5·2	12·2	4·4
	Mangolds 1941–59.		Sugar beet 1946–59.			

Without farmyard manure, the PK fertilisers increased the yields of both crops, but only of mangolds with farmyard manure. The increases were greater, and the decreases less, at the higher levels of nitrogen. Farmyard manure has behaved consistently with sugar beet and mangolds in decreasing for each crop the responses to PK fertilisers, but with sugar beet by enough to de-

crease yield. This effect must not be attributed solely to either source of P and K (fertilisers or farmyard manure), but to the total amount of P and K from the two sources. At the levels of N used, the total was excessive for sugar beet and near the level for maximum yield for mangolds. The effect on sugar beet of PK fertilisers + FYM was therefore an intensification of the effect on mangolds. This difference between the two crops is also reflected in the responses to N fertilisers (Table 12).

Sugar beet responded much less to N fertilisers in the presence of PK fertilisers + FYM than with either alone, whereas mangolds gave similar responses.

Sugar percentages were determined only in the last six crops of beet. The mean for the experiment was 16·7, and the main effects of the manurial treatments were:

	Changes in percentage of sugar
Nitrogen fertilisers	−0·4
Potassium sulphate	+0·3
Sodium chloride + magnesium sulphate ...	+0·4

Nutrient Contents of the Crops

Chemical analyses were not made of the mangolds from 1904 to 1940, and previous accounts of Barnfield dealt with analyses made in some years between 1876 and 1902. Those published by Lawes and Gilbert did not include all plots, and full sets of analyses, tops and roots separately, were first made in the last 2 years of the experiment, 1958 and 1959. The sugar beet were also analysed. Results for the 2 years are not adequate to represent the period 1941–59, but they do provide a good indication of the main treatment differences, because treatment effects on yield in the 2 years resembled those for the longer period.

Although the concentrations of nutrients in plants are important, there is too little information about mangolds (and many other crops) for the results to be interpreted satisfactorily in terms of levels of deficiency, excess or toxicity. The discussion here is mainly on the effects of the manurial treatments on the amounts per acre of each nutrient in the crops, with only an occasional reference to percentages in the crops and to the distribution of nutrients between tops and roots.

Table 13 gives the yields of dry matter and the nitrogen and phosphorus contents of plants from some of the main manurial treatments.

Although farmyard manure contained nearly twice as much nitrogen as each of the N fertilisers, the crop on the plot receiving FYM only took up little more than half as much nitrogen as the crop receiving N fertilisers. This is different from the early years 1876–1900, when the amounts of N taken up from the two sources of N were nearly equal. In the early years and at the end of the experiment more nitrogen was taken up by mangolds from sodium nitrate than from ammonium sulphate; the extra showed more in the percentage of nitrogen in the crop than in increase in yield. The figures in Table 13 cannot be used to determine precisely what

TABLE 13

Dry-matter yields and N *and* P *contents of mangolds and sugar beet, Barnfield 1958–59 means*

Strip	Series:	cwt./acre Dry matter O	N	A	lb. element/acre Nitrogen O	N	A	Phosphorus O	N	A
					Mangolds tops + roots					
1 FYM ...	...	32	60	62	48	142	136	11	22	23
2 FYM, P, K	...	34	59	54	56	151	137	12	20	23
4 P, K, Na, Mg	...	15	49	42	18	102	76	4	16	16
6 P, K ...	...	12	40	42	14	89	72	3	13	15
7 P, Na, Mg ...	...	14	43	41	15	86	74	4	13	15
					Sugar beet, tops + roots					
1 FYM ...	...	51	80	77	62	140	148	10	16	18
2 FYM, P, K	...	44	72	70	56	136	140	9	16	20
4 P, K, Na, Mg	...	15	63	54	18	102	76	3	11	11
6 P, K ...	...	13	51	54	15	80	76	2	9	10
7 P, Na, Mg ...	...	17	67	60	18	122	83	3	12	10

percentage was recovered by the crop of the nitrogen applied in a single dressing of N fertiliser or FYM. In this experiment the tops of the crop are ploughed back into the soil each autumn, and how much nitrogen this makes available to the crop in the next year is not known. Also, FYM and N fertiliser dressings exceeding 0·5 cwt. N/acre leave nitrogen residues in the soil, the availabilities of which cannot be estimated in this experiment.

The crops contained only about $\frac{1}{6}$ as much phosphorus as nitrogen. The percentages of P in the crops grown with ammonium sulphate were consistently higher than with sodium nitrate (mean increase 0·02% P), but the P removed per acre was almost identical for the two N fertilisers. The figures in Table 13 confirm that farmyard manure provides enough P for mangolds and sugar beet, and superphosphate applied to the farmyard-manure plots did not increase the amounts of P in the crops. Further, applying an N fertiliser to the farmyard-manure plots, which doubled the yield of dry matter, also doubled the uptake of P per acre. The farmyard manure (14 tons/acre) contained 25 lb. P and the superphosphate ($3\frac{1}{2}$ cwt./acre) 30 lb. P. At this level of application together with the P residues in the soil from previous applications the crops took up similar amounts of P from the organic manure and the inorganic fertiliser. The availability of the phosphorus in the two materials needs testing with smaller dressings, but their similar behaviour on Barnfield accords with the analysis of Rothamsted farmyard manure, in which about $\frac{1}{3}$ of the P is water-soluble.

Table 14 shows the potassium, sodium and magnesium contents of mangold and sugar-beet crops from plots which received no farmyard manure. The mineral manure treatments were the four combinations of (1) potassium sulphate (204 lb. K/acre) and (2) sodium chloride with magnesium sulphate (78 lb. Na and 20 lb. Mg/acre); all plots received N and P fertilisers.

The figures in the table are averages of three of the Series treatments, A (ammonium sulphate), C (rape cake) and AC (ammonium sulphate and rape cake). Each Series treatment crossed all the mineral manure Strip treatments, but Series N (sodium nitrate)

TABLE 14

Contents of* K, Na *and* Mg *in mangolds and sugar beet, Barnfield means for 1958–59*

Strip	lb. element/acre in tops + roots K Mangolds	K Sugar beet	Na Mangolds	Na Sugar beet	Mg Mangolds	Mg Sugar beet
4, K, Na + Mg ...	192	134	58	39	10	12
5 —	71 †	80 †	20	21	7	13
6 K	187	138	22	19	8	11
7 Na + Mg ...	79	60	99	74	11	13

K 204 lb. K/acre as potassium sulphate.
Na 78 lb. Na/acre as sodium chloride.
* Means of three series: ammonium sulphate, rape cake, ammonium sulphate + rape cake. All plots received P as superphosphate.
† Rape cake supplied 25–30 lb. K/acre and K contents on Strip 5 are therefore greater than the amounts of K released from soil minerals.

and Series O (no nitrogen) were omitted from the averages, the first because it supplied sodium and the second because very poor crops are produced on this soil when nitrogen is withheld.

With potassium sulphate, the mangolds contained 40% more K than the sugar beet, but without contained similar amounts. Similarly, mangolds contained more Na than sugar beet where sodium chloride was given, but not otherwise.

Table 15 shows increases in K, Na and Mg produced by the fertilisers.

TABLE 15

Effect of potassium sulphate and sodium chloride on the uptakes of K *and* Na *by mangolds and sugar beet, Barnfield means 1958 and 1959*

Effect of *	lb. element/acre (tops + roots) Mangolds K	Mangolds Na	Mangolds Mg	Sugar beet K	Sugar beet Na	Sugar beet Mg
K in absence of Na + Mg	116	2	1	58	−2	−2
Na + Mg in absence of K	8	80	4	−20	53	0
K and Na + Mg present ...	121	38	3	54	18	1

* In the presence of N and P
K at 204 lb./acre
Na at 78 lb./acre
Mg at 20 lb./acre

The extra amounts of K in the crops were for mangolds equal to one-half and for sugar beet one-quarter of the 204-lb. dressing of fertiliser K. Where Na fertiliser was applied without K, the extra amount of Na in the mangolds equalled all the 78 lb. of Na applied as sodium chloride; for sugar beet the extra was two-thirds of the dressing. The Mg changes in lb./acre were small. A main feature of the results in Table 15 is the contrast in behaviour of K and Na in the presence of each other. For each crop the extra amount of K from K fertiliser was the same with and without Na fertiliser (mangolds 116 lb. and 121 lb., sugar beet 58 lb. and 54 lb.), but the extra amount of Na from Na fertiliser was only one-half for mangolds, and one-third for sugar beet, with K fertiliser as without (mangolds 38 lb. and 80 lb., sugar beet 18 lb. and 53 lb.). This comparison

(K_2SO_4 *v.* NaCl) could not be made in the early years because Strip 7 was treated differently since 1903 than previously. By comparing the uptakes in the early years (1878–83) of K and Na from the sodium nitrate and ammonium sulphate sections of the mineral manure strips, Watson showed that K and Na each depressed the uptake of the other. This result was true for the same plots in 1958–59, but the Na depressed K uptake less at the end of the experiment than in the early years. The differences between the two comparisons (NaCl *v.* K_2SO_4 and $NaNO_3$ *v.* $K_2SO_4 + (NH_4)_2SO_4$), in the effect of one ion on the other, however, are not inconsistent. They reflect differences in the Na : K ratios produced in the soil by the different Na fertilisers. The $NaNO_3$ dressing supplied twice as much Na as the sodium chloride dressing. K residues from K_2SO_4 accumulated in the soil, but excess Na was almost wholly leached out, so that the difference in Na : K ratio between the two sets of plots widened as the experiment continued.

Of the total potassium in farmyard manures from the Rothamsted Farm, 70–80% is soluble in water and over 90% in ammonium acetate solution. Nearly all the sodium is water-soluble. The simple design of the Barnfield Experiment does not provide a satisfactory comparison of the effectiveness of potassium in the two forms, fertiliser and farmyard manure, as they operated in the presence of different amounts of nitrogen. Good comparisons require well-established N response curves and K uptakes. However, an approximate adjustment to the K uptake for the difference in N levels indicated that the availabilities of the K from the two sources were similar. For similar reasons an approximate value only, 15 lb. Na/acre, can be given for the uptake of sodium by mangolds from farmyard manure.

Mg fertiliser is thought to affect yields of mangolds on Barnfield little, but leaf symptoms of magnesium deficiency have been seen on some of the plots of the sodium nitrate series. The percentages of magnesium in the leaves of mangolds and sugar beet 1958–59, were less for all plots with sodium nitrate than with ammonium sulphate, except where farmyard manure was applied. The mean values, per cent magnesium in dry matter for each series, were:

Leaves	Sodium nitrate	Ammonium sulphate
	Mg % in dry matter	
Mangold	0·28	0·43
Sugar beet	0·17	0·24

Table 16 gives the uptakes by mangolds (tops + roots) of Mg on both nitrogen series, for plots with and without Mg fertiliser, and without farmyard manure.

The difference between the series was small with Mg fertiliser (0·5 lb. Mg/acre), but much larger without (1·8 lb. Mg). The NH_4 ion and Na ion apparently affected the uptake of the Mg ion similarly where there was adequate available Mg, but ammonium sulphate and sodium nitrate probably differed in their action on the non-exchangeable Mg in the soil. The difference (1·8 lb. Mg) on the plots without Mg fertiliser can be accounted for by the acidifying action of ammonium sulphate. Local chalk contains 0·4% Mg, and

1·5–2 lb. Mg would be released from the chalk in the soil by the dressing of ammonium sulphate (420 lb. acre). The uptakes for sugar beet on the two series differ as with mangolds, 0·1 lb. Mg acre with and 1·8 without Mg fertiliser. Table 16 shows no effect on uptake by mangolds of Mg by K fertiliser but with sugar beet K decreased uptake by 1 lb. Mg/acre.

About 2 lb. Mg acre were taken up from the farmyard manure.

TABLE 16

Uptake of Mg *by mangolds on ammonium sulphate and sodium nitrate series in presence and absence of* Mg *and* K, *Barnfield 1958–59*

	Strip 4 (P, K, Na, Mg)	Strip 7 (P, Na, Mg)	Strip 5 (P)	Strip 6 (P, K)	Effect of Na, Mg
	lb. Mg/acre				
Ammonium sulphate	7·7	7·6	6·4	6·4	1·3
Sodium nitrate ...	7·2	7·2	4·6	4·7	2·6
Difference	0·5	0·4	1·8	1·7	

EFFECT OF THE MANURIAL TREATMENTS ON THE SOIL

In the classification of the soils of the Rothamsted Farm by the Soil Survey of England and Wales, the soil of Barnfield, except " the valley ", belongs to the Batcombe Series, with a flinty clay loam surface soil and a yellow-red flinty clay subsoil with vari-coloured mottling at varying depths below 9 inches. In " the valley " the soil belongs to the Charity Series, which differs from the Batcombe Series mainly in the subsoil. The subsoil of the Charity Series is a brown flinty loam or clay loam down to at least 24 inches. About half of each plot which received sodium nitrate is in the Charity Series.

A pH survey of Barnfield in 1953–54 showed that areas within the ammonium sulphate and ammonium sulphate + rape cake series (A and AC) were acid (pH 5 in water). The soils of the other nitrogen series contained chalk, up to 2% $CaCO_3$. A dressing of ground chalk, 5 tons/acre, was applied to Series A and AC in 1956. In 1958, when soil samples were taken for detailed chemical analysis, the pH values for all plots were between 7 and 8. Table 17 gives analysis of the soils for total N, soluble and total P; ammonium acetate-soluble K and Na for the 0–9-inch depth. Soils from other depths (9–12, 12–18, 18–21 inches) were also analysed, and references to the results are made in the text.

Nitrogen

The nitrogen content of the surface soil of Barnfield unmanured plots was 0·01% N lower than the comparable soils of the Broadbalk Wheat and Hoosfield Barley experiments. The effect of inorganic fertilisers (N, P, K) on the N content of the soil was the same in the three experiments, a small gain of 0·01% N. Although the mangold experiment began in 1876, farmyard manure was applied to the site of Strips 1 and 2 from 1856 and the gain in soil nitrogen in 1958 over the unmanured soil was 0·14% N. This increase is less than on

TABLE 17

Analyses of surface soil, 0–9 inches, Barnfield, 1958

Series		1 FYM	2 FYM, PK	Strip 4 P, K, Na, Mg	5 P	6 P, K	7 P, Na, Mg	8 O
				Total N %				
O	...	0·230	0·237	0·088	0·092	0·087	0·088	0·092
N	...	0·240	0·242	0·101	0·098	0·096	0·096	0·096
A	...	0·258	0·252	0·096	0·094	0·092	0·098	0·098
AC	...	0·286	0·277	0·121	0·116	0·123	0·124	0·116
C	...	0·282	0·274	0·111	0·118	0·119	0·121	0·120
				Total P mg./100 g.				
O	...	124	195	122	120	122	123	78
N	...	122	184	120	128	132	135	61
A	...	133	185	117	115	110	117	61
AC	...	154	205	135	144	141	154	94
C	...	155	217	140	153	156	163	94
				P soluble in 0·01*M*-$CaCl_2$ g. mols. per litre $\times 10^{-6}$				
O	...	13·2	14·9	2·0	1·5	1·9	1·9	0·6
N	...	10·0	20·0	2·4	2·1	2·0	2·7	0·4
A	...	15·2	32·3	7·3	4·2	4·5	4·5	0·5
AC	...	17·9	34·0	20·1	9·6	14·3	12·4	5·4
C	...	19·9	44·8	7·0	3·7	4·5	5·4	4·1
				P soluble in 0·5*M*-$NaHCO_3$ mg./100 g.				
O	...	8·3	14·0	5·9	6·1	6·6	6·1	2·3
N	...	7·4	13·2	5·6	5·9	5·4	5·7	1·3
A	...	10·2	16·3	9·9	8·7	8·6	8·0	1·7
AC	...	13·0	17·3	11·7	12·3	15·0	12·2	6·2
C	...	12·8	19·8	9·8	8·8	9·3	9·3	5·6
				P soluble in acetic acid–sodium acetate, pH 4·8 mg./100 g.				
O	...	4·5	8·5	2·0	1·5	2·0	1·4	0·3
N	...	3·0	7·5	2·1	2·0	2·5	2·2	0·2
A	...	3·7	5·9	2·1	1·7	1·6	1·6	0·2
Ac	...	3·4	4·5	2·1	2·8	3·2	3·6	1·3
C	...	4·8	8·0	4·5	3·6	4·1	3·5	1·6
				P soluble in 0·3*N*-HCl mg./100 g.				
O	...	25	91	35	41	39	36	10
N	...	28	74	38	45	32	37	6
A	...	31	44	26	29	25	22	2
AC	...	37	54	22	41	37	54	12
C	...	40	81	40	23	60	63	13
				K soluble in *N*-ammonium acetate mg./100 g.				
O	...	54	89	62	17	65	35	18
N	...	33	76	45	13	58	15	12
A	...	24	67	48	12	43	11	10
AC	...	26	64	39	13	35	12	11
C	...	31	84	53	13	53	13	10
				Na soluble in *N*-ammonium acetate mg./100 g.				
O	...	2·0	1·9	2·0	1·1	0·9	2·6	1·0
N	...	5·8	5·3	4·8	4·1	3·9	5·0	3·8
A	...	1·0	1·0	2·2	0·6	0·7	2·6	0·6
AC	...	1·0	1·2	2·2	0·6	0·6	1·7	0·4
C	...	1·5	1·3	2·2	0·6	0·7	2·3	0·6

O, no nitrogen; N, sodium nitrate; A, ammonium sulphate; AC, ammonium sulphate + rape cake; C, rape cake.

Hoosfield (0·17% N), partly because of the wider row spacing of the crop on Barnfield and partly because of the deep cultivation in 1929–30 to about 12 inches. The still smaller increase (0·13% N) on

Broadbalk with a narrow row crop was caused by the fallowing scheme introduced into the experiment. The extra nitrogen in the soil of the farmyard-manure plots on Barnfield was equal to about one-quarter of the amount applied in the organic manure. On Barnfield, rape cake gave an increase in soil nitrogen similar to the increases on Broadbalk and Hoosfield (0·03% N). The extra nitrogen in the rape-cake plots of Barnfield and of Broadbalk was equal to one-tenth of the nitrogen applied; on Hoosfield the fraction was one-fifth, as the dressing of rape cake was half that of the other fields.

Phosphorus

The site of the no P strip (8) of the Mangold Experiment received phosphate between 1843 and 1852 (Table 2, footnote 4), more than 30 years before this experiment began. At the end of the experiment no part of this strip was as exhausted of P as the no-P plots of the Agdell and Exhaustion Land Experiments. Even on the parts of this strip where sodium nitrate and ammonium sulphate were applied, the total P and $NaHCO_3$-soluble P values of the soil were only a little less than those of the P-residue plots of the Exhaustion Land Experiment, on which the responses by crops to P fertiliser in 1957–58 were small except for potatoes. As two-fifths of Strip 8 also received P, contained in the rape-cake dressing, each year from 1845 to 1959, there is now on Barnfield only a little land at moderately low levels of P and none at very low levels.

Although the sodium nitrate series started in 1861, after the other nitrogen series, the site had received the same amounts of strip manures, because from 1843 these manures had been applied in " the valley " from Series O to Series A. From 1843 to 1852 Lawes and Gilbert used " the valley " land for other experiments in which phosphate manures were applied as dressings across Strips 4–7. In 1958 there were large P residues in the soil from the early cross dressings. The mean value for total P for Strips 4, 5, 6 and 7 of the nitrate series was 128 mg./100 g.; the corresponding values for the ammonium sulphate (Series A) and the no-nitrogen plots (Series O) were 115 mg. and 122 mg. The P uptake by the crops in 1958–59 for the two series (A and N) were almost identical, and therefore none of the extra total P in the soils of the nitrate series should be attributed to the two N fertilisers affecting uptake differently. The soils of the ammonium sulphate plots, however, contained more $CaCl_2$-soluble and $NaHCO_3$-soluble P than the sodium nitrate plots, even though they contained less total P (Strips 4–7). The differences were equally large for P derived from superphosphate and from farmyard manure, but the difference in $CaCl_2$-soluble P on the no-P plots was very small. In contrast to the neutral and alkaline extractants, two acid extractants, CH_3COOH–CH_3COONa (pH 4·8) and 0·3*N*-HCl, dissolved more P from the sodium nitrate plots than from the ammonium sulphate plots. Apparently none of the extractants correctly assessed the available P, but mangolds and sugar beet may be sensitive only to drastic changes in soluble P at very high levels, such as the levels in the P fertiliser and farmyard-manure plots.

There were other differences in the effects of manurial treatments

on soluble P, such as the higher values on the farmyard-manure plots than on the superphosphate plots for the same increase in total P (Series O, N, C). There were also further differences between extractants, but it is not possible to decide from the yield and uptake figures in this experiment whether the differences in soluble P by any one method or the differences between methods are important.

Potassium

The Mangold Experiment was the only Classical experiment in which fertilisers were applied to farmyard-manure plots. Much more K consequently accumulated in these plots than elsewhere. Table 17 shows the amounts of K soluble in ammonium acetate for all the surface soil samples (0–9 inches) taken in 1958. The highest values (up to 89 mg. K/100 g. soil) were in the soils of the FYM + PK plots (Strip 2), the next highest were the K fertiliser plots and then the plots with farmyard manure only. The unmanured plot on Barnfield contained more soluble K than the corresponding plots on Broadbalk, Hoosfield, Exhaustion Land and Agdell (Barnfield 18, the other fields 8–10 mg. K/100 g. soil). Strip 7, where from 1903 the fertiliser treatment was P, Na, Mg but earlier included K, had a large residue of fertiliser K (17 mg. K/100 g. soil) in the plot without N fertiliser, but not where nitrogen was applied.

The effects of sodium chloride and sodium nitrate on the amounts of soluble K in the soils which received potassium sulphate were in accord with the uptakes of potassium by the crops. At the high level of soluble K in these plots, applying sodium chloride (78 lb. Na/acre) did not change the amount of soluble K accumulated from the annual dressings of K fertiliser. The increases in soluble K, with and without added sodium (means of Series A, C and AC) were:

Increase in soluble K *on* K *fertiliser plots* (*mg./100 g. soil*)

Soil depth (in.)	Sodium chloride Present	Absent
0–9	34·8	35·0
0–21	20·8	19·2

As on Broadbalk and Hoosfield, considerable K passed into the subsoil on Barnfield, but adding sodium chloride did not affect its distribution. Where more sodium was applied as sodium nitrate (141 lb. Na/acre), the soluble K differed from the ammonium sulphate plots:

Differences between sodium nitrate (*Series N*) *and ammonium sulphate* (*Series A*) *plots in* K *uptakes and soil* K

Strip	K uptake (lb./acre)	Series N–A Soil K soluble in ammonium acetate 0–21 in. (mg./100 g.)
1 (FYM)	−70	4
2 (FYM, P, K)	−38	10
4 (P, K, Na, Mg)	16	−7
6 (P, K)	−27	5

Three of the four sodium nitrate plots had more soluble K, but the fourth on Strip 4 had less. The different result for Strip 4 is consistent with the uptake results, for more K was taken up on this strip with sodium nitrate but less on the other strips. At the lower levels of soluble K in the soils of plots without K fertiliser, sodium nitrate had smaller effects, an increase of 3 mg. soluble K in the surface soil but a small decrease of 1 mg. for full depth 0–21 inches. The crops from two short periods only were analysed, the very early years and the last 2 years, and a satisfactory balance sheet for potassium in this experiment cannot be made. However, at the end of the experiment there was a good linear relation between the amounts of K removed in the roots of the five nitrogen series (leaves are ploughed in) and the amounts of soluble K in the soils for each of the three treatments FYM, K fertiliser and FYM + K fertiliser. The ratio of K uptake by crop to soluble K in the soil differed for each treatment because the amounts of K applied differed. The ratio for each treatment probably changed only gradually during the course of the experiment, because the much soluble K in the soils in 1958 could only come from the accumulation of K residues over a long period. The very small uptake of K on the no-nitrogen series of the K fertiliser treatment allows an estimate to be made of the increase in soluble K were no crop present. The average increase for the surface soil + subsoil would be 40–45 mg. K/100 g. soil. This is only one-seventh of the K applied during the years 1845–1959, the difference is loss by " fixation " in the soil and loss in drainage water. Unfortunately the important comparison of the reactions of farmyard-manure K and fertiliser K with soil cannot be obtained in this experiment, mainly because only one rate of each material was tested, and each supplied a different amount of potassium. There is no information on the proportion of K " fixed " in the soil in the presence of organic matter, but experiments in the laboratory showed that the extra organic matter in the soils of the farmyard-manure plots had no significant effect, in soil-water suspensions, on the equilibrium between water-soluble K and exchangeable K. The ratio was indeed nearly the same for all the soils containing 15–80 mg. K, soluble in ammonium acetate, per 100 g. soil; at the higher levels the ratio increased slightly.

Sodium

The results of soil analysis for sodium and potassium illustrate the difference in the retention of the ions of the two elements by the soil. Even on the no-nitrogen series, where very little sodium was removed by carting off the roots, the extra sodium in the soil from annual applications of sodium chloride for a century was only 1–1·5 mg. Na soluble in ammonium acetate per 100 g. soil. On the sodium nitrate plots, where nearly twice the amount of sodium was applied, the increase in soluble sodium over the ammonium sulphate plots was 3·5 mg. Na/100 g. soil. On the farmyard-manure plots also there was a small increase in sodium, 0·5–1·0 mg. Na compared with the fertiliser plots which had not received sodium chloride or sodium nitrate. The average content of sodium in the farmyard manure used in the experiment is not known, but in samples from the

Rothamsted Farm during the past 3 years, the amount in a 14-ton dressing was 15–20 lb.

Extending the Use of the Barnfield Site

In the Mangold Experiment the two comparisons of sodium (as sodium chloride and sodium nitrate) with potassium each had a defect. Magnesium sulphate was always applied where sodium chloride was given, and no separate test of magnesium was made. Without either Mg fertiliser or the acidifying action of ammonium sulphate, only 5 lb. Mg/acre were taken up by mangolds and 7 lb. by sugar beet. The latter figure is low even for medium yields of sugar beet, so that the effect of magnesium on yield cannot be dismissed as negligible for either crop. With sodium nitrate the possibility of a difference in the effects of ammonium and nitrate nitrogen on yield may have interfered with the comparison of sodium and potassium. More nitrogen was taken up by the crops from the nitrate than the ammonium salt, and as the dressing 86 lb. N/acre was not high, the extra nitrogen in the crops may not have been merely luxury uptake.

Barnfield contains soils differing widely in the amounts of readily soluble potassium, and so provides an opportunity for extending the work on the value for different crops of K residues in the soil.

On the FYM + PK strip the levels of soluble P and K in the soil were very high, and these, together with the amounts in new dressings of FYM + PK fertiliser (60 lb. P, 350 lb. K), adversely affected the yield of sugar beet. Whether this effect can be reversed by increasing the rate of application of nitrogen can only be decided by further experiment. Though mangolds were not affected in the same way as sugar beet, larger yields might be obtained by giving more nitrogen.

The highest yields on Barnfield were on the FYM + N fertiliser plots, but increasing levels of inorganic nitrogen were not tested to see whether this form of nitrogen only could give equally high yields. Several characteristics of farmyard manure have not been assessed, such as the value of the sodium and magnesium it contains and the higher solubility of the P (in $CaCl_2$ and $NaHCO_3$) in the soil from the farmyard-manure plots than from the superphosphate plots on the no-nitrogen and sodium nitrate series.

Proposals for modifying the cropping and manuring scheme on Barnfield were considered by the Field Plots Committee, and consent to make changes was given by the Lawes Trust Committee. Two changes are proposed for the first stage in extending the scope of the investigations. They are the substitution of several rates of nitrogen as ammonium sulphate and sodium nitrate for the single rate, and growing potatoes on half plots alongside the mangolds.

References

(1) Lawes, J. B. & Gilbert, J. H. (1895). Agricultural investigations at Rothamsted during a period of 50 years. *U.S. D.A. Bull.* No. 22 and *Trans. Highl. agric. Soc. Scot.* Ser. 5, **7**, 11–354.

(2) Hall, A. D. (1902). The continuous growth of mangolds for twenty-seven years on the same land, Barnfield, Rothamsted. *J. R. agric. Soc.* **63**, 27–59.

(3) Watson, D. J. & Russell, E. J. (1943–46). The Rothamsted Experiments on Mangolds 1872–1940. Part I. Effect of manures on yield of roots. *Emp. J. exp. Agric.* **11**, 49–64.
(4) Watson, D. J. & Russell, E. J. (1943–46). The Rothamsted Experiments on mangolds 1872–1940. Part 2. Effect of manures on the growth of the plant. *Emp. J. exp. Agric.* **11**, 65–77.
(5) Watson, D. J. & Russell, E. J. (1943–46). The Rothamsted Experiments on mangolds 1872–1940. Part 3. Causes of variation of yield. *Emp. J. exp. Agric.* **13**, 61–79.
(6) Watson, D. J. & Russell, E. J. (1943–46). The Rothamsted Experiments on Mangolds 1872–1940. Part 4. The composition of the mangolds grown on Barnfield. (i) The dry matter content of leaves and roots. *Emp. J. exp. Agric.* **14**, 49–56.
(7) Watson, D. J. & Russell, E. J. (1943–46). The Rothamsted Experiments on Mangolds 1872–1940. Part 4. (ii) The nitrogen content of leaves and roots. *Emp. J. exp. Agric.* **14**, 57–70.
(8) Kalamkar, R. J. (1933). A statistical examination of the yield of mangolds from Barnfield at Rothamsted. *J. agric. Sci.* **23**, 161–175.

ABSTRACTS OF PAPERS

Physics Department

General Papers

1.1. Currie, J. A. 1962. The importance of aeration in providing the right conditions for plant growth. *J. Sci. Fd Agric.*, **13**.

1.2. Monteith, J. L. (1960). Research on crop evaporation in Israel. (Report prepared for the Government of Israel under the United Nations Programme of Technical Assistance.)

Research Papers

1.3. Cashen, G. H. (1961). Electric charges of clays. *Chem. & Ind.*, 1732–1737.

Kaolin possesses an isomorphous replacement charge, and develops additional negative and positive charges in alkaline and acid conditions respectively. The residual positive edge charge after washing is small, and because exchangeable aluminium is always found, the kaolin decomposes when the edges discharge. Illites and montmorillonites behave similarly. After an acid water treatment of clay minerals the action of deflocculants is primarily to replace exchangeable aluminium and not to neutralise positive edge charges.

1.4. Currie, J. A. (1961). Gaseous diffusion in the aeration of aggregated soils. *Soil Sci.*, **92**, 40–45.

Adequate aeration depends partly on active soil depth and a macro-diffusion coefficient, and partly on micro-structure and diffusion within crumbs. Formal analysis of the diffusion problem is based on three assumptions: i that the soil has a crumb structure, *i.e.* that there are inter-crumb channels permitting aeration of the soil matrix as a whole; ii that respiratory activity is uniform throughout the crumb; and iii that there is a single critical concentration at which all aerobic activity ceases in all organisms.

The analysis gives some idea of the physics of "optimum crumb size". The lower limit is set by the minimum inter-crumb pore size that will permit free drainage at field capacity. The upper limit is set by potential respiration of the soil and by the structure of the crumbs and their water content. No universally acceptable specification of optimum size is possible.

1.5. Monteith, J. L. (1962). Dew: facts and fallacies. In *Water Relations of Plants*. British Ecological Society.

The maximum or "potential" condensation rate on a horizontal surface of negligible heat capacity, realised when the atmosphere is saturated, is independent of wind speed and is directly proportional to net radiative loss R. The constant of proportionality is temperature dependent and, assuming an empirical expression for R, calculated potential condensation is $0{\cdot}067 \pm 0{\cdot}007$ mm. hr. between 0° and 25°, with a maximum at 12°. In slightly unsaturated air condensation falls below the "potential" value by an amount depending on relative humidity and wind speed. Theoretical values are consistent with measurements at Rothamsted and elsewhere, but much larger values physically impossible, are found in the literature.

Maximum condensation on artificial dew gauges reached 0·4 mm. night, apparently irrespective of climate. When dew gauges have approximately the same thermal properties as leaves and are exposed close to the crop canopy they may give useful estimates of dew amount and duration when the atmosphere is saturated. Potential condensation on non-horizontal bodies such as isolated trees and shrubs can be found from the effective radiative loss.

and is always greater than the potential condensation on a horizontal surface with the same projected area. The closed canopy of a field crop collects approximately the same dew as an equivalent projected surface.

Two transfer processes for condensation are " distillation " (quasi-molecular diffusion of water vapour from warm soil to cooler leaves) and " dewfall " (turbulent transfer of vapour from atmosphere to leaves). In a saturated atmosphere the dewfall/distillation ratio depends on the relative thermal properties of atmosphere and soil, effectively on wind speed. On a calm, clear night dewfall is negligible; with a light wind, dewfall may exceed distillation; with a high wind, leaves do not cool sufficiently for dew to form. Dewfall conserves soil moisture; distillation accelerates its loss.

Dry soil can absorb water vapour directly from the atmosphere, but this water is not " available " to plant roots. The absorption of vapour by leaves has been demonstrated in the laboratory; in nature, the absorption of dew is more important. This absorption decreases water deficits and prolongs plant life when soil moisture is critically low. It may also stimulate growth, but conclusive field evidence is lacking. Without absorption, dewfall can lower transpiration in the early morning but cannot protect plants from severe water stress throughout the day.

1.6. MONTEITH, J. L. & SZEICZ, G. (1962). Simple devices for radiation measurement and integration. *Arch. Met., Wien*, B**12**.

Simple thermopiles formed by copper-plating a constantan wire were used to build a solarimeter and a net radiometer. Output was 5–10 mV/cal. cm.$^{-2}$ min.$^{-1}$, adequate to operate a small portable galvanometer for spot readings, a continuously recording potentiometer or, for integration, a Siemens electrolytic meter. The net radiometer was unventilated, but when oscillated manually, output was independent of wind speed. With two solarimeters in a null-balance circuit, reflection and transmission coefficients of a field crop were read directly on a dial. The Siemens meter had a back E.M.F. of about 350 μV and a temperature coefficient of resistance of $-2{\cdot}5\%/°$ C. A circuit was designed to integrate solarimeter output and the standard error of weekly readings was only ± 40 cal./cm.^{2}.

1.7. PENMAN, H. L. (1961). Weather, plant and soil factors in hydrology. *Weather*, **16**, 207–219.

The components in the water balance of a catchment area are discussed, with some detail on the separation of stored water from soil water. The evaporation term is considered both energetically and aerodynamically, and a new combined general formula is given, thought to be applicable to any kind of surface. Examples used and discussed are: comparison of transpiration from papyrus and evaporation from open water (Sudan); comparison of irrigated and non-irrigated herbage (Congo); the water balance of a British catchment over 15 years (Stour); and comparison of evaporation from grass and forest (Germany). None of the three comparisons reveals any major difference in evaporation rates—the local climate is dominant.

1.8. PENMAN, H. L. (1962). Physical properties of soils. In " The Soil ". Symposium of Institutes of Biology, Chemistry & Physics, March 1961.

Soil properties are in three groups: particle properties (texture), pore properties (structure) and quasi-homogeneous properties. The interactions of texture and structure are discussed in terms of available water, soil structure and stability, and aeration. At field capacity the " available water " should be as large as possible to permit maximum resistance to drought, and the crumbs that hold this water must be small enough to ensure that what is defined as available is also accessible, and to avoid risk of anaerobic conditions. Good management may open the soil, beneficially, but the slowness of return to closer packing depends on crumb stability.

1.9. PENMAN, H. L. (1962). Woburn Irrigation 1951–1959. Part I. Purpose, design and weather. Part II. Results for grass. Part III. Results for rotation crops. *J. agric. Sci.*, **58**,

An extended summary of the agronomic results in these three papers was given in the main report for 1960, pp. 33–38.

1.10. Rose, D. A. (1962). The effect of dissolved salts on water movement. In *Water Relations of Plants*. British Ecological Society.

Experiments confirm theoretical prediction that the presence of solutes decreases the diffusion rate of water, the decrease being proportional to the solute concentration and inversely proportional to the diffusion coefficient of the solute ions in the porous system. There seems no serious risk that the osmotic potential gradient set up by the presence of soil fertilisers will successfully compete with the plant roots in drawing water out of the region between them.

1.11. Schofield, R. K. & Taylor, A. W. (1961). A method for measurement of the calcium deficit in saline soils. *J. Soil Sci.*, **12**, 269–275.

The calcium deficit of a saline soil is defined as the amount of calcium which must be supplied to saturate the soil with divalent cations. A method is described whereby this amount can be measured in samples of unwashed saline soil and used to estimate the amount of gypsum needed in the field to prevent deterioration of the soil structure while it is being leached into a salt-free condition.

Chemistry Department

General Papers

2.1. Barrow, N. J. (1961). Phosphorus in soil organic matter. *Soils & Fert.*, **24**, 169–173.

2.2. Cooke, G. W. (1961). Soils and Fertilisers. *J. R. agric. Soc.*, **122**, 150–174.

2.3. Cooke, G. W. (1960). Field experiments on phosphate fertilisers in the United Kingdom. *Proc. Third int. Congr. int. Ass. Res. Phosphates*, pp. 150–154.

2.4. Cooke, G. W. (1960). Recent research on the value of phosphate reserves in soils. *Proc. Third int. Congr. int. Ass. Res. Phosphates*, pp. 184–191.

2.5. Cooke, G. W. (1961). The use of nitrogen fertilisers in Britain and their effects on the yield and composition of crops. *Agrochimica*, **5**, 189–206.

Research Papers

2.6. Arnold, P. W. & Close, B. M. (1961). Release of non-exchangeable potassium from some British soils cropped in the glasshouse. *J. agric. Sci.*, **57**, 295–304.

Continuous cropping with perennial ryegrass in the glasshouse measured the release of non-exchangeable potassium from twenty soils representative of a wide variety of soil series. Releases of non-exchangeable K ranged from almost none to >2,000 lb. K/acre. The main reason for variations in the potassium-releasing powers of the soils was traced to differences in the amount and K content of the finer clay fractions. Small K-contents in the fine clay, and small contents of fine clay, were associated with small releases of non-exchangeable K. Accumulated potash fertiliser residues, or the presence of such minerals as glauconite, can be responsible for the good potassium-releasing powers of some soils. Many soils appear to contain at least two categories of useful non-exchangeable K.

2.7. Arnold, P. W. & Close, B. M. (1961). Potassium-releasing power of soils from the Agdell rotation experiment assessed by glasshouse cropping. *J. agric. Sci.*, **57**, 381–386.

On cropping Agdell experiment top-soils to exhaustion with perennial ryegrass in the glasshouse, the total K uptakes were directly proportional to the initial exchangeable K contents of the soils. The ability of the Agdell top-

soils to release non-exchangeable K under glasshouse conditions decreased in the order PK-rotation with fallow > NPK-rotation with fallow > PK-rotation with clover > NPK-rotation with clover > no-fertiliser-rotation with fallow = no-fertiliser rotation with clover. Releases of non-exchangeable K were at least 2·5 times larger than the falls in the exchangeable K for all the Agdell soils. In a " take-down " experiment in the glasshouse on a soil receiving K fertiliser each year in the Saxmundham Rotation I Experiment, loosely held non-exchangeable K was released at a near-linear rate. At least a part of the loosely held non-exchangeable K in the Agdell soils was also released at a near-linear rate.

2.8. Chakravarti, S. N. & Talibudeen, O. (1961). Phosphate interaction with clay minerals. Part I. Effects of a 10^{-5} molar phosphate solution on two and three layer minerals at pH values 3, 4 and 5. *Soil Sci.*, **92**, 232–242.

Hydrogen-ion uptake from solution at pH values 3, 4 and 5 by two 1 : 1-type and two 2 : 1-type clay minerals was measured over 9 months with and without the addition of a 10^{-5} *M*-potassium phosphate solution. Approximately linear relationships were observed between nett proton uptake (N.P.U.) and time at each pH level, and between $-\log$ (N.P.U.) and the pH of the system at any sampling time, whereas phosphate uptake and N.P.U. were unrelated. However, the N.P.U. per g. per year was much larger in the phosphate systems at the higher pH values, where adsorbed $H_2PO_4^-$ ions significantly increased the hydrogen-ion activity in the electrical double layer. The total surface area of the minerals was only very qualitatively related to their N.P.U./g./year. The dimensions of platelets in the two kaolinites and the glauconite laths are discussed with respect to phosphate uptake in the pH range 3–5, assuming that N.P.U. is primarily due to " octahedral edge-face " area. Linear relationships were invariably observed between $-\log (M^{3+})$ and pH, where M = Al or Fe. A polymeric chain model of variable length is proposed for cations of aluminium adsorbed on the octahedral edge faces of the minerals containing 17 atoms of the metal for the kaolinite and glauconite and 4 atoms for the montmorillonite. Corresponding figures for the iron polymeric ion are 8 and 1 respectively.

2.9. Gasser, J. K. R. (1961). Transformation, leaching and uptake of fertiliser nitrogen applied in autumn and spring to winter wheat on a heavy soil. *J. Sci. Fd Agric.*, **12**, 375–380.

The concentrations of ammonium and nitrate in the surface layer (0–6 inches) of a heavy soil with and without fertiliser-N were measured from October 1957 to September 1958 on plots growing winter wheat and in bare soil. Ammonium sulphate or calcium nitrate supplying 100 lb. of N/acre was applied in the autumn, in the spring or half in autumn + half in spring. Both forms of fertiliser applied in the autumn were lost from the surface soil by the following March. Autumn-applied nitrogen was not taken up by the wheat during the autumn or winter. Nitrogen applied in the spring was rapidly taken up by the crop, but remained in the surface soil of the bare plots until June, when prolonged and heavy rain leached the nitrate into the lower soil layer. At the time the ears emerged much more mineral nitrogen had been lost from the soil top-dressed with fertiliser in the spring than was accounted for by the increase in nitrogen uptake by the above-ground parts of the wheat. The yields of grain and straw at harvest were not increased by the nitrogen fertilisers, whenever applied. The nitrogen contents of both grain and straw were increased by applying fertilisers, and there were consistent but small increases in the total nitrogen uptake by the wheat on the fertilised plots. The uptake of fertiliser nitrogen was greatest in the samples taken at ear emergence when, on average, 27 lb. of N/acre of the 100 lb. applied were recovered. At harvest wheat from the fertilised plots contained 18 lb. of N/acre less than at ear emergence.

2.10. Gasser, J. K. R. (1961). Soil nitrogen. VI. Correlations between laboratory measurements of soil mineral-N and crop yields and responses in pot and field experiments. *J. Sci. Fd Agric.*, **12**, 562–573.

Soil samples from sites of field experiments testing N-fertilisers for barley, potatoes, kale and grass were used for pot experiments with ryegrass and also

to measure "available"-N in the laboratory. Mineral-N in the fresh soil (Mineral-N_{fresh}, and the increases when fresh or re-wetted air-dry soils were incubated ($\triangle$ Mineral-N_{fresh} or $\triangle$ Mineral-$N_{air\text{-}dry}$) were determined. These were more highly correlated with organic C than with total N content of the soils. Among "available"-N measurements, Mineral-N_{fresh} and $\triangle$ Mineral-$N_{air\text{-}dry}$ were most correlated with one another. The yields of dry matter and N uptake of ryegrass grown in unfertilised soil, or with two rates of applied N, were significantly correlated with Mineral-N_{fresh} or $\triangle$ Mineral-$N_{air\text{-}dry}$ at each level of nitrogen, but not with $\triangle$ Mineral-N_{fresh}.

The unfertilised yields of barley in field experiments were significantly correlated with Mineral-N_{fresh}, $\triangle$ Mineral-$N_{air\text{-}dry}$, and total N; responses by barley to 0·5 cwt. of N/acre were significantly negatively correlated with all three "available"-N measurements and with total N. Unfertilised yields of potatoes were significantly correlated with the three "available"-N measurements and responses to 1·0 cwt. of N/acre were significantly negatively correlated with $\triangle$ Mineral-$N_{air\text{-}dry}$ and total N. Mineral-N_{fresh} and $\triangle$ Mineral-$N_{air\text{-}dry}$ are suggested as useful measurements for advisory purposes.

2.11. Gasser, J. K. R. (1961). Effects of air-drying and air-dry storage on the mineralisable-nitrogen of soils. *J. Sci. Fd Agric.*, **12**, 778–784.

Samples of eight soils were air-dried and stored in brown-paper or in sealed polythene bags for periods up to 98 weeks. Portions of the fresh and re-wetted air-dry soils were incubated at 25° for 10–84 days. The soils were extracted before and after incubation and the increase in mineral-N (NH_4^+-N + NO_3^--N) content ($\triangle$ Mineral-N) was measured. Air-drying increased $\triangle$ Mineral-N. Air-dry storage further increased $\triangle$ Mineral-N, the value increasing with the period stored, but the mineralisable-N of soils kept in sealed polythene bags increased less than that of soils in paper bags, the increases occurring only in the easily mineralisable-N; most of the extra mineral-N was formed during the first 10 days' incubation, and all by 42 days; thereafter the air-dried soils had the same rate of mineralisation as the fresh soils. The mineral-N content of the air-dry soils increased with storage. In a further similar test with fourteen soils, air-dried and stored in brown-paper bags for periods up to 32 weeks, the mean value of $\triangle$ Mineral-N varied irregularly with time of storage up to 18 weeks, but thereafter increased with increasing period of storage before incubation. The mineral-N content of the air-dry soils varied, the maximum value being found in the samples stored for 12 weeks.

2.12. Heintze, S. G. (1961). Studies on cation-exchange capacities of roots. *Plant & Soil*, **13**, 365–383.

Enzymic breakdown of pectin caused an initial rapid pH drift towards the acid side when hydrogen-ion-saturated roots were neutralised. Buffer curves of root suspensions showed that at least some of the acidic groups of root surfaces are derived from carboxylic groups of pectin acid. Roots showed greater affinity for Ba^{--} than for K^--ions at concentrations below normality. Estimations of CEC values from exchange reactions between roots and the latter cations were more affected by altering the conditions during exchange than were those from exchange with Ba^{--}. Isotopic exchange between roots saturated with non-labelled calcium and Ca^{45} suggested that adsorbed calcium is held in an exchangeable and not in chelated form. Changes in CEC caused by ageing of plants, or by varying nutrient levels in the growing medium, agreed in general, both in direction and magnitude, with the findings of other workers. High CEC values were associated with low K/Ca ratios of plant tops or of the whole plant, and *vice versa*, when comparisons were restricted within the same K-level of the growing medium. This relationship was reversed for CEC values and K/Ca ratios of roots of clover and ryegrass. A correlation coefficient that was just significant was found in some comparisons for the relationship between CEC values of two species and the inverse ratio of the K-contents of their tops.

2.13. Jenkinson, D. S. (1960). The production of ryegrass labelled with carbon-14. *Plant & Soil*, **13**, 279–290.

The construction and operation of a growth chamber for producing plant material labelled with carbon-14 to a specified degree of uniformity is described.

The specific activity of the plant material is measured by a method based on scintillation counting.

2.14. Mattingly, G. E. G. & Pinkerton, A. (1961). Some relationships between isotopically exchangeable phosphate, soil analysis and crop growth in the greenhouse. *J. Sci. Fd Agric.*, **12**, 772–777.

An experiment on perennial ryegrass in small pots compared yields of grass and responses to added superphosphate with the analyses of fifteen soils and with their total isotopically exchangeable phosphate ("A" value). The highest positive correlations between yields, and negative correlations between responses to added superphosphate, were obtained with "A" values. The phosphate extracted by 0·5*M*-$NaHCO_3$, 0·5*N*-acetic acid–sodium acetate, 0·3*N*-HCl and 0·002*N*-H_2SO_4 (reagents 1–4, respectively) also correlated well with yield. Yield and phosphate soluble in 0·5*N*-acetic acid (reagent 5) were not significantly correlated. The soils were mixed with ^{32}P-labelled superphosphate, stored for 30 days at field moisture capacity, air-dried and extracted with the five reagents listed above. The amounts of $^{32}PO_4$ that exchanged with soil phosphate during extraction were compared with the amounts that exchanged in soil similarly treated and cropped with ryegrass in the greenhouse. More soil phosphate exchanged during extraction with reagents 3–5 in the laboratory than in the greenhouse experiment. These reagents dissolved soil phosphate, or exposed new surfaces on the soil, from which phosphate is not taken up by ryegrass. The soil phosphate that exchanged in reagents 1 or 2 was more closely correlated with, and nearly equal to, the "A" value of the soils enriched with superphosphate. Reagent 1 did not increase soil phosphate surfaces in most soils, but reagent 2 dissolved some phosphate, which did not exchange in the greenhouse, from soils containing more than 4% $CaCO_3$.

2.15. Nowakowski, T. Z. (1961). The effect of different nitrogenous fertilisers, applied as solids or solutions, on the yield and nitrate-N content of established grass and newly-sown ryegrass. *J. agric. Sci.*, **56**, 287–292.

Experiments on permanent grass and newly-sown Italian ryegrass compared ammonium hydroxide solution, with ammonium sulphate, ammonium nitrate, calcium nitrate and urea, applied at 56 and 112 lb. N/acre as solids, and also when dissolved in water to give a final N content of 5%. Ammonium hydroxide solution containing 5% N damaged established grass severely and did not increase dry-matter yields; when applied to the seedbed before sowing Italian ryegrass, ammonium hydroxide solution did not affect germination, but yields were lower than with other N fertilisers. On permanent grass all other fertilisers significantly increased dry-matter yields and N uptake at both cuts. The form of N fertiliser did not significantly affect dry-matter yields or N uptake of grass of the first cut. The method of application (i.e., solid or liquid) did not affect dry-matter yields, except that ammonium nitrate in solution gave a significantly higher yield than did the solid form at the second cut; the grass had higher N content with solid forms than with solutions. The grass took up more N from solid forms than from solutions except with ammonium nitrate at the second cut. Delaying the N application by 20 days decreased dry-matter yields considerably and increased the N content of the grass. In the experiment with newly-sown Italian ryegrass all fertilisers significantly increased dry-matter yields and N uptake at both cuts. Dry-matter yields of the first cut were significantly higher with calcium nitrate than with all other fertilisers. The dry-matter yields of the second cut obtained with calcium nitrate, ammonium nitrate and urea did not differ significantly; the yield with ammonium sulphate was significantly lower than that with calcium nitrate and ammonium nitrate, but was not significantly lower than the yield with urea. The differences in N taken up by plants from different fertilisers were in the order: calcium nitrate > ammonium nitrate > urea > ammonium sulphate. More N was taken up from solid forms than from solutions.

The grass which received 56 lb. N/acre contained little nitrate, and differences between treatments were small. The nitrate content of grass receiving 112 lb. N/acre depended on the form of the fertilisers and the time and method

of application. Nitrate contents were highest with calcium nitrate (1,384 p.p.m.) or ammonium nitrate (1,418 p.p.m.), lowest with ammonium sulphate (386 p.p.m.) and intermediate with urea (724 p.p.m.). The nitrate content of permanent and new-sown grass was greater with solid fertilisers than with solutions. Delaying the application of fertiliser increased the amount of nitrate in the grass.

2.16. Widdowson, F. V. & Penny, A. (1960). Experiments with urea on spring barley. *Exp. Husbandry*, No. 5, 22–26.

Four spring barley experiments compared combine-drilled dressings of urea and ammonium sulphate supplying 0·25, 0·5 or 0·75 cwt. N acre. Urea was consistently inferior to ammonium sulphate. Urea supplying 0·5 cwt. N/acre checked early growth; at 0·75 cwt. N acre urea checked growth severely and some plants died. These checks occurred at each centre, but their effects were less, in terms of yields at harvest, with very early sowing. Ammonium sulphate checked growth slightly at the heaviest rate of application. The nitrogen percentages of grain grown with urea or ammonium sulphate were similar with dressings of 0·25 or 0·50 cwt. N/acre, but with dressings of 0·75 cwt. N/acre, urea gave grain containing more nitrogen.

2.17. Widdowson, F. V., Penny, A. & Williams, R. J. B. (1961). Applying nitrogen fertilisers for spring barley. *J. agric. Sci.*, **56**, 39–47.

Fifteen experiments on spring barley (mainly Proctor) done from 1957 to 1959, compared alternative methods of applying 0·3, 0·6 and 0·9 cwt. N acre. Combine-drilling 0·3 or 0·6 cwt. N/acre as ammonium sulphate produced higher mean yields than broadcasting, but drilling 0·9 cwt. N acre checked early growth and reduced mean yields in two of the three seasons. Supplementing 0·3 cwt. N/acre by combine-drill with an equivalent top-dressing of " Nitro-Chalk " consistently outyielded a single drilled or broadcast dressing supplying the same total quantity of N. Supplementing the heavier drilled dressing (0·6 cwt. N/acre) with 0·3 cwt. N acre top-dressing was less advantageous, and yields were depressed in the wet season of 1958. Gains from N fertilisers were recorded at every centre. Dressings in excess of 0·6 cwt. N/acre gave only small gains in yield and caused severe lodging in 1958. The experiments support our previous work on local soils, in which 0·5–0·6 cwt. N/acre was optimum for barley. The N content of barley receiving no N fertiliser ranged from 1·52 to 2·16%, with a mean value of 1·70%. A seedbed dressing of 0·3 cwt. N/acre had little effect on N content and decreased values at several centres; heavier dressings gave appreciable gains in N content. All dressings of N increased the proportion of small grains; top-dressings gave more small grains than broadcasting; drilling gave samples of intermediate value.

2.18. Widdowson, F. V., Penny, A. & Williams, R. J. B. (1961). Experiments with nitrogen and potash on barley. *J. agric. Sci.*, **57**, 29–33.

Four experiments in 1958 and five in 1959 compared responses to K (as combine-drilled muriate of potash) in the absence of N and in the presence of single and double doses of N (as broadcast ammonium sulphate) on soils low in acid-soluble K. Responses to 0·5 cwt. K_2O/acre were obtained at 6 centres (2 significant), but the effects of a further 0·5 cwt. K_2O/acre varied more, and gains and losses (each at 4 centres) were almost equally balanced. Gains from N were associated with previous cropping. N_1 raised yields at 7 centres (6 significantly) but N_2 raised yields further at only 5 centres (3 significantly) and depressed yields significantly at 3 centres where barley followed roots or ley. Potash did little to improve strength of straw and standing capacity in a wet season (1958) and had little effect on size of grain, whereas N increased lodging and decreased average size of grain. Increases in K uptake were associated with yield increases, whereas increases in N uptake were associated with both higher N percentage in grain and higher yields.

2.19. Widdowson, F. V., Penny, A. & Williams, R. J. B. (1961). Autumn nitrogen for winter wheat. *J. agric. Sci.*, **57**, 329–334.

Fourteen experiments with winter wheat on heavy-land farms from 1958 to 1960 compared autumn dressings of ammonium sulphate with equivalent early (March) or late (May) spring top-dressings. Dressings applied on two or all three dates of application were also compared. Consistent and significant gains in yield from low (0·5 or 0·6 cwt. N/acre) and high (1·0 or 1·2 cwt. N/acre) levels were obtained at most centres, which were on fields under arable rotation. With the low level of N, gains in yield were greatest from a single May top-dressing. There was no gain from dividing the dressing. With the high level of N, dressings divided between autumn–May or March–May were best. March–May was the most consistently satisfactory treatment and gave the highest mean increases in yield in 1959 and 1960, but in 1958 autumn–May was better. Single May dressings gave slightly lower yields. There was no advantage from dividing N between all three dates of application. Single applications of N in autumn gave lower yields than single applications in spring; supplementing autumn N with a late spring top-dressing gave almost the same yield as giving all the N in spring. The percentage of N in the grain was highest with a late top-dressing of fertiliser-N, lowest with autumn N and intermediate with March top-dressings.

2.20. Williams, R. J. B. & Cooke, G. W. (1961). Some effects of farmyard manure and of grass residues on soil structure. *Soil Sci.*, **92**, 30–39.

Clay and sandy soils that had contrasted continuous treatments were used in laboratory measurements of pore sizes, of aggregate stability and permeability, and of clod strengths. Thin sections showed close packing occurred in natural aggregates of sandy soils under continuous arable cultivation; sands were improved by farmyard manure (FYM) or by grass roots, and all the clay soils tested had some large pores. Pore-size measurements showed that checks to root growth were unlikely with the clays used, but were possible with the arable sands. A simple and quick practical test was developed to identify soils where unstable structure may lead to poor crops. The percentage loss in pore space that occurred after twice wetting and draining an aggregated soil sample measured structural instability, such as may lead to close packing in wet weather; the rate water passed through soil after the slaking test measured permeability and indicated whether trouble may be expected from small pores in packed soil. Continuous grass was more effective than annual dressings of FYM in making soils more permeable, in making aggregates stable to water, and in weakening clods formed by mechanical ill-treatment. Sandy soil under continuous arable cultivation without FYM gave very unstable aggregates and packed badly after slaking, but FYM given once in 5 years improved stability and permeability only slightly. Six months after sowing grass the sandy soil was much more stable, but still packed badly; 3 years under grass stabilised structure completely, but most of the improvement was lost a year after ploughing. For high yields of arable crops on soils that are unstable and poorly permeable, more organic matter may be needed than is given by the residues of arable crops grown on the land; the extra organic matter is better provided by a period under grass than by occasional dressings of FYM.

Pedology Department

Book

3.1. Brown, G. (1961). *The X-ray identification and crystal structures of clay minerals.* Edited by G. Brown. 2nd edition. London: Mineralogical Society.

General Papers

3.2. Muir, A. (1961). The podzol and podzolic soils. *Advanc. Agron.*, **13**, 1–56.

3.3. Ng Siew Kee & Bloomfield, C. (1961). Mobilisation of trace elements in waterlogged soils. *Chem. & Ind.*, 252–253.

Research Papers

3.4. Ng Siew Kee & Bloomfield, C. (1961). The solution of some minor element oxides by decomposing plant materials. *Geochim. et cosmoch. Acta.* **24**, 206–225.

Oxides of several trace elements are dissolved by the action of anaerobically fermenting plant material and, less effectively, by sterile aqueous extracts of undecomposed plant material. The dissolved metals seem to be in complex form, not colloidally dispersed. The solutions are stable to atmospheric oxidation, but in the presence of ferrous iron aeration causes co-precipitation of the trace elements with ferric oxide. The order of ease of co-precipitation appears to be Mo, V > Zn > Cu > Co > Ni. Sorption on ferric oxide is appreciable in some conditions. Copper and nickel are irreversibly sorbed from fermentation solutions by plant fibre.

3.5. Weir, A. H., Nixon, H. L. & Woods, R. D. (1962). The measurement of dispersed clay flakes with the electron microscope. *Clays and Clay Minerals.* London: Pergamon Press, pp. 419–423.

The shadow lengths of dispersed flakes of the layer-lattice mineral, allevardite, were measured with the electron microscope. Details of the experimental technique are given, and the importance is stressed of using samples free from very small material. The measurements of flake thickness agreed well with estimates of the basal spacing of the collapsed lattice obtained by X-ray diffraction analysis, and dispersion of allevardite produced suspended flakes 19 Å thick, corresponding in thickness to the basic structural unit of two 2 : 1 layers.

Soil Microbiology Department

General Papers

4.1. Brown, M. E. & Cooper, R. (1960). Microbiology of the soil. *Rep. Progr. appl. Chem.*, **45**, 551–568.

4.2. Mosse, B. (1962). Vesicular–arbuscular mycorrhiza and some problems associated with their study. [In Italian] *Nuovo G. bot. ital.* (In the press.)

Research Papers

4.3. Brown, M. E., Burlingham, S. K. & Jackson, R. M. (1962). Studies on *Azotobacter* species in soil. 1. Comparison of media and techniques for counting *Azotobacter* in soil. *Plant & Soil.* (In the press.)

The highest counts of *Azotobacter* were obtained from soil suspensions shaken in sterile distilled water containing 10 g. glass beads and plated on to glucose agar. Mannitol was rejected as a suitable substrate in agar media because it gives lower counts of *Azotobacter* than glucose, an effect further enhanced by drying the agar plates. A clear medium free from precipitated phosphate and $CaCO_3$ is recommended for the agar-plate method; the *Azotobacter* count is affected by the phosphate concentration.

The dilution-tube method is less accurate than the agar-plate, but more convenient when many soil samples have to be examined.

4.4. Ljunggren, H. (1961). Transfer of virulence in *Rhizobium trifolii*. *Nature, Lond.*, **191**, 623.

An avirulent (non-nodulating) strain of clover nodule bacteria (Strain Bart. A) was induced to form nodules on white clover by treatment with a cell-free preparation made from an unrelated virulent strain (Strain 226).

Bacteria isolated from nodules produced by the changed strain retained their virulence after subculture, without further treatment. Neither the avirulent mutant strain (which was rough) nor its smooth virulent form after treatment agglutinated with an antiserum made against a related virulent strain (Strain A121111). Both the changed strain and the strain providing the inducing preparation required pantothenic acid, whereas the avirulent mutant did not. These results suggest that the change in virulence is a genetic transformation mediated by DNA present in the cell-free preparation.

4.5. Meiklejohn, J. (1962). Microbiology of the nitrogen cycle in some Ghana soils. *Emp. J. exp. Agric.* (In the press.)

The bacteria concerned in the nitrogen cycle were counted in Ghana forest and grassland soils. These two types of vegetation produce very different levels of soil fertility. The forest soils are very fertile, with a high content of exchangeable bases, organic matter and nitrogen. Grassland soils are much less fertile, and lack available nitrogen.

The forest and grassland soils differ little in their content of nitrogen fixers; the numbers are generally high, and slightly higher in grassland soils. Anaerobic nitrogen fixers (Clostridia) were always present. Of the aerobic nitrogen fixers, *Azotobacter* was dominant in neutral soils and *Beijerinchia* in acid soils. Cells of *Azotobacter* and *Beijerinchia* were found on the leaves of forest plants.

Forest and grassland soils contain very different numbers of nitrifiers. As long as soil cover is maintained, forest soils contain many ammonia- and nitrite-oxidisers, whereas grassland soils contain few ammonia-oxidisers and very few or no nitrite-oxidisers. None of the grassland samples taken after the start of the rainy season contained any nitrite-oxidisers. The lack of available nitrogen in Ghana grassland soils seems mainly because there are no bacteria able to oxidise nitrite to nitrate.

4.6. Mosse, B. (1962). The establishment of vesicular-arbuscular mycorrhiza under aseptic conditions. *J. gen. Microbiol.*, **27**, 509–520.

The establishment of vesicular–arbuscular mycorrhizal infections by inoculation with germinated resting spores of an *Endogone* species was investigated under microbiologically controlled conditions; pure two-membered cultures were obtained for the first time.

Seedlings were grown in a nitrogen-deficient inorganic salt medium, and under these conditions the fungus was unable to form an appressorium and to penetrate the plant roots unless an inoculum of a *Pseudomonas* sp. was also added. Adding soluble nitrogen to the medium completely inhibited root penetration, even in the presence of the bacteria. Various sterile filtrates could be used to replace the bacterial inoculum, but these induced only few infections per plant.

Mycorrhizal roots grew more vigorously than non-mycorrhizal roots of the same seedling. They were longer and more profusely branched. At first mycorrhizal infections were predominantly arbuscular, but many prominent vesicles developed as the seedlings declined, and then the fungus grew out of infected roots and colonised the agar. The fungus could not be subcultured without a living host.

4.7. Nutman, P. S. (1962). The relation between root hair infection by *Rhizobium* and nodulation in *Trifolium* and *Vicia*. *Proc. roy. Soc.* (In the press.)

The infection of the root-hairs of young seedlings of twelve species of *Trifolium* and of *Vicia hirsuta* was examined. The amount of infection (numbers of hairs containing infection-threads) at 2 weeks varied much between species of host, and was less affected by bacterial strain; host and strain differences were independent. In most hosts a high proportion of infections did not result in nodule formation.

The relative rates of increase in numbers of infected hairs was constant before nodulation began. The duration of this pre-nodulation phase of exponential increase in infection, but not its rate, differed between species. Nodulation (and lateral root formation) caused an abrupt lowering of the

initial rate of infection. Post-nodulation infection also increased exponentially. Low concentrations of nitrate nitrogen delayed nodulation and increased the numbers of hairs infected.

Infected hairs were not randomly distributed along the root, infection beginning at a few well-separated points. Later infections occurred near these primary foci to give zones of infection, which then spread up and down the root. The positions of nodules or lateral roots were not related to the foci of hair infection.

Botany Department

Research Papers

5.1. Humphries, E. C. (1961). Effects of quality of light on development of roots on dwarf bean hypocotyls in presence and absence of boron. *Nature, Lond.*, **190**, 701–703.

The effect of boron on root formation on hypocotyls of dwarf French bean was influenced by the quality of light received by the plant. Incandescent light given before or after the hypocotyls were excised decreased the number and weight of adventitious roots on plants without boron, but had no effect on root formation of plants given boron. Plants in fluorescent light produced similar numbers of roots whether boron was supplied or not.

5.2. Humphries, E. C. & French, S. A. W. (1961). Effect of nitrogen supply on the response of Majestic potato to gibberellic acid. *Ann. appl. Biol.*, **49**, 331–339.

Potato plants sprayed with gibberellic acid (GA) were given extra nitrogen either through the soil (as ammonium nitrate) or through the leaves (as urea). GA increased the initial production of dry matter, but the effect did not persist even with additional N. The number of leaves on lateral branches was decreased by GA partly because leaf production on laterals at lower nodes was inhibited. N increased the rate of leaf production on lateral branches; the soil application doubled the leaf number, and the urea increased it by 50%. GA, but not N, increased the area of a main stem or lateral stem leaf; however, nitrogen produced the largest total leaf area because it produced more leaves. There was no evidence for any interaction between GA and N, either in the effect on leaf number or total leaf area. The fall in total N content per unit area caused by GA found in an earlier experiment was confirmed, and additional N did not arrest this decline. Loss of efficiency of GA-sprayed plants is unlikely to result from indirect deficiency caused by rapid leaf expansion.

5.3. Orchard, B. (1961). An automatic device for measuring leaf area. *J. exp. Bot.*, **12**, 458–464.

The design and construction of a digital device, which measures the area of leaves by scanning with a rapidly moving spot of light, is described.

5.4. Thorne, G. N. (1962). Survival of tillers and distribution of dry matter between ear and shoot of barley varieties. *Ann. Bot. Lond.*, **26**, 37–54.

Plants of Plumage Archer barley grown in pots produced more shoots than did Proctor, but had fewer ears at maturity, because some shoots died about 7 days before ear emergence. The number and position on the plant of the shoots that died were consistent for particular growing conditions. Shoots that died were not always the last to be produced. There were no consistent differences in dry weight, leaf area, nitrogen content or apex development between shoots that did and did not survive; nor did removing developing ears on three older shoots affect the survival of other shoots. Growth of Plumage Archer plants was not checked by death of shoots; dry matter, nitrogen and leaf area were redistributed so that increase in surviving shoots compensated for losses in the dead shoots.

The dry-weight ratio of ear to shoot was smaller for Proctor than for Plumage Archer at ear emergence and anthesis, but at maturity it was greater

for Proctor, both when ears were shaded to prevent them photosynthesising and when they were unshaded. The varietal difference in ear : shoot dry-weight ratio was reversed because the relative growth-rate of ears of Proctor was greater and because more dry matter was lost from its shoots. Both changes may have been caused by translocation to the ear of a greater proportion of the assimilate from the shoots of Proctor than of Plumage Archer. Leaves of Proctor appeared to be more efficient in producing dry matter for the ear than those of Plumage Archer.

5.5. Thorne, G. N. (1962). Effect of applying nitrogen to cereals in the spring or at ear emergence. *J. agric. Sci.*, **58**, 89–96.

Nitrogen applied at ear emergence to winter wheat or spring barley grown in pots with various levels of basal N fertiliser increased grain and total dry weight much less than similar amounts of N applied in March or April. No N was absorbed after ear emergence from unfertilised soil, or from the early application, and at maturity equal amounts of N had been absorbed from early and late applications.

Early N increased final ear number by increasing the number at emergence and also increased grain size. Late N had negligible effect on yield of ears present when it was applied, and caused the production of new shoots with small ears. N applied at both times increased leaf-area duration after ear emergence similarly: early N by increasing area at ear emergence and late N by delaying senescence of existing shoots and causing production of new shoots. The efficiency in grain production of the leaf area present after ear emergence was less with late than with early N, mainly because of the low efficiency of the shoots produced after ear emergence.

These results differ from those of field experiments, in which early and late N usually increase grain yield similarly, probably because in the field there were no late unproductive tillers and all the late N was utilised in increasing grain yield of existing shoots. Another difference was that N uptake from soil in the field continued until maturity.

5.6. Watson, D. J. & French, S. A. W. (1962). An attempt to increase yield by controlling leaf area index. *Ann. appl. Biol.*, **50**, 1–10.

Previous work showed that the leaf area index (L) of kale crops in their later stages of growth can be much above the optimum for dry matter production, which was between 3 and 3·5. When L was held close to 3·5 during July–September 1955, by repeated thinning of plants, the total yield of dry matter, including thinnings, was increased by about 6%. When thinning was more severe yield was not increased. In a similar period in 1956 thinning that held L between 3·5 and 4 or between 3 and 3·5 did not increase total yield of dry matter, because in this year optimal L was much higher than before. The explanation of the seasonal variation in optimal L is not known.

5.7. Wheeler, A. W. (1961). Effect of light quality on the growth and growth-substance content of plants. *J. exp. Bot.*, **12**, 217–225.

The main effect of incandescent light on most of several species and varieties of plants grown in cabinets illuminated by fluorescent light was to increase the length of internodes. Although leaf area was little affected, incandescent light increased the dry weight of most plants.

In dwarf French bean plants the longer internodes of plants grown with additional incandescent light were associated with higher contents of gibberellic acid-like and indolylacetic acid-like growth substances.

5.8. Wheeler, A. W. (1962). Growth activity of the gibberellins of dwarf French bean, potato and lettuce. *J. exp. Bot.*, **13**, 36–44.

Zones with similar Rf to gibberellic acid (GA) on chromatograms of ethyl acetate extracts of dwarf French bean and potato leaves and stems and lettuce heads all promoted growth of disks of etiolated dwarf French bean leaves in darkness. The presence of a gibberellin was confirmed by tests with stems of dwarf pea, but that the substance was not GA was shown by the lack of effect in the tests with lettuce hypocotyls. The tests with dwarf maize

mutants (effects on d-3 and d-5 but not d-1) identified it as gibberellin A_5. The gibberellin content of the tissues was estimated from calibration of the growth tests with GA.

Biochemistry Department

Thesis

6.1. Singh, N. (1961). Factors affecting the extractability and stability of leaf proteins.

General Papers

6.2. Holden, M. (1961). Biochemical changes in Cocoa fermentation. In *The Chemistry of Cocoa*. BFMIRA Scientific and Technical Surveys No. 38, 31–40.

6.3. Pirie, N. W. (1962). Prerequisites for virus classification. In "Microbial Classification", 374–393. Symposium No. 12. Society of General Microbiology.

6.4. Pirie, N. W. (1962). The role of leaves in human nutrition. *King's News*, **26**, 10.

6.5. Pirie, N. W. (1961). Solar wind and terrestrial oxygen. *Nature, Lond.*, **190**, 706.

6.6. Pirie, N. W. (1961). Green leaves give edible protein. *Envoy*, **6**, 8–21.

6.7. Pirie, N. W. (1961). The selection and use of leafy crops as a source of protein for Man. *Proc. V int. Cong. Biochem. (Moscow)*.

6.8. Pirie, N. W. (1962). The principles of classification illustrated by the problem of virus classification. *Perspectives in Biology and Medicine*. (In the press.)

6.9. Pirie, N. W. (1962). Indigenous Foods. *Advanc. Sci., Lond.*, **18**, 467–475.

6.10. Pirie, N. W. (1961). Progress in biochemical engineering broadens our choice of crop plants. *Econ. Bot.*, **15**, 302–310.

6.11. Pirie, N. W. (1962). Glutathione. *Proc. roy. Soc. B.* (In the press.)

Research Papers

6.12. Byers, M. & Jenkins, G. (1961). Effect of gibberellic acid on the extraction of protein from the leaves of spring vetches (*Vicia sativa* L.). *J. Sci. Fd Agric.*, **12**, 656–661.

In connection with the production of leaf-protein in quantity, the effect of gibberellic acid on the yield of dry matter and crude protein, and on the extractability of the protein, was studied with spring vetches (*Vicia sativa* L.).

A single spraying with gibberellic acid did not significantly affect the dry matter or crude protein in the foliage at the first cut, nor did it affect the extraction.

The yields of dry matter and crude protein at the second cut were significantly lowered when the crop had been sprayed before the first cut. Two additional sprayings of gibberellic acid after the first cut further decreased these yields at the second cut. In both these cases the yields of extracted

protein at the second cut and the combined yields from the first and second cuts were significantly lower than the corresponding yields from the unsprayed plants. Spraying with gibberellic acid before the second cut only did not affect the dry matter, but lowered both the yields of crude and extracted protein, although the combined yields from the two cuts were not significantly lowered.

Hence, gibberellic acid not only fails to increase the leaf-protein extractable from spring vetches, but under certain conditions decreases it.

6.13. Holden, M. (1962). Separation by paper chromatography of chlorophylls *a* and *b* and some of their breakdown products. *Biochim. biophys. Acta.*, **56**, 378–379.

Chlorophylls, pheophytins, chlorophyllides and pheophorbides are separated by varying the proportions of petroleum ether, benzene and acetone in the running solvent and the atmosphere of the tank.

6.14. Morrison, J. E. & Pirie, N. W. (1962). A unit for the quick freezing and drying of 8 kg. lots of moist protein. In *Freeze-Drying of Foodstuffs*, London: Borough Polytechnic. (In the press.)

A unit is described in which moist protein is distributed among four or more industrial scale glass tubes connected to a manifold; this is connected to an extended-surface heat exchanger immersed in a tank of dilute methanol at −35°. When the system is evacuated the heat exchanger is able to cope in less than a minute with the heat liberated when the mass of protein freezes. This greatly improves the texture of the product.

6.15. Pierpoint, W. S. (1962). Mitochondrial preparations from the leaves of tobacco (*Nicotiana tabacum*). 4. Separation of some components by density gradient centrifugation. *Biochem. J.*, **82**, 143–147.

Preparations from tobacco leaves were centrifuged in sucrose density gradients and resolved into chloroplasts, chloroplast fragments and particles, presumably mitochondria, containing succinoxidase activity. The centrifugation sedimented fumarase as if it were attached to the mitochondria, and cytochrome oxidase as if it were associated with mitochondria and with mitochondrial fragments. No cytochrome oxidase activity was detected in chloroplasts either before or after disruption with digitonin. Glycollic oxidase did not sediment appreciably during the centrifugation, and it could not be detected in intact chloroplasts.

Plant Pathology Department

Book

7.1. Gregory, P. H. (1961). *The Microbiology of the Atmosphere*. London: Leonard Hill.

General Papers

7.2. Bawden, F. C. (1961). Some effects of changing environment on the behaviour of plant viruses. In Symposia of the Society for General Microbiology No. XI, "Microbial Reaction to Environment", pp. 296–311.

7.3. Glynne, Mary D. & (Moore, F. Joan). (1961.) *Melanospora damnosa* associated with *Fusarium culmorum* on cereals. *Plant Path.*, **10**, 168.

7.4. Gregory, P. H. & Bunce, Maureen E. (1961). The microflora of hay. Abstr. in *Acta allerg., Kbh.*, **16**, 74.

7.5. Harrison, B. D. (1961). Some aspects of virus multiplication in inoculated leaves. *Proc. 4th Conf. Potato Virus Diseases.* Braunschweig 1960, 50–59.

7.6. Hirst, J. M. (1961). The aerobiology of *Puccinia graminis* uredospores. *Trans. Brit. mycol. Soc.*, **44**, 138–140.

Research Papers

7.7. Bawden, F. C. (1961). The susceptibility of *Rhoeo discolor* to infection by tobacco mosaic virus. *J. biol. Chem.*, **236**, 2760–2761.

Rhoeo discolor was reported in the U.S.A. to be insusceptible to infection by whole tobacco mosaic virus, but susceptible when inoculated with the virus nucleic acid, implying: (*a*) that infection necessarily entails the nucleic acid separating from the protein of the virus, and that (*b*) some plants may resist infection because they do not contain systems able to disrupt the virus particles. However, *R. discolor* was found to be susceptible, but a poor host in which virus multiplication becomes readily demonstrable only when inoculated leaves are brightly illuminated. Multiplication is easier to establish unequivocally with inocula of nucleic acid than of intact virus, because results are not complicated by residual infectivity from the inoculum.

7.8. Bawden, F. C. & Sinha, R. C. (1961). Effects of ultraviolet radiation on infection by intact and phenol-disrupted red clover mottle virus. *Virology*, **14**, 198–206.

Exposing French bean leaves to ultra-violet radiation after inoculation with red clover mottle virus decreased numbers of infections more than did exposure before inoculation. The decrease produced by a given dose of radiation differed with plants in different physiological states. Treatments that increased susceptibility to infection also increased the effects of the radiation. Irradiation before inoculation affected lesion numbers similarly whether the inoculum was intact or phenol-disrupted virus, provided the leaves were in the dark after irradiation, but when leaves were in the light effects were much greater with disrupted virus. Intact virus is apparently better able than disrupted virus to survive, while light restores the capacity of leaves to support infection. The effects of photoreactivation depended on the radiation dose; leaves given small doses before inoculation and then exposed to visible light produced more lesions than the controls when the inoculum was intact virus, but usually fewer when it was disrupted virus. Irradiation immediately after inoculation decreased lesions more with disrupted virus than with intact virus, but infection centres initiated by disrupted virus increased their resistance sooner and more rapidly. Infection centres initiated by intact virus retained their original susceptibility for about 2 hours at 24°–28° and 6–8 hours at 16°. At 32° resistance did not increase even after 22 hours; plants placed at 24° after 22 hours at 32° produced about half as many lesions as those kept at 24° continuously after inoculation. At 32°, infection centres initiated by disrupted virus also failed to increase their resistance to inactivation by the radiation, and few survived 4 hours, even in unirradiated leaves. Hence, whatever may happen at lower temperatures, intact virus seems not to dissociate into protein and nucleic acid in leaves at 32°.

7.9. (Broadbent, L.) & Heathcote, G. D. (1961). Winged aphids trapped in potato fields, 1942–1959. *Ent. exp. & appl.*, **4**, 226–237.

Sticky aphid-traps were operated over potato crops at Rothamsted during 18 years, and elsewhere for shorter periods, to get information about the activity of *Myzus persicae* in relation to the spread of virus diseases. Numbers of total aphids, *M. persicae*, *Aphis fabae* and *Brevicoryne brassicae*, caught per week are given. Annual rhythms in aphid numbers were unpredictable, although there was a tendency for *A. fabae* to be few during the year after one in which they had been numerous. *M. persicae* were few in summer when they and their predators or parasites had been numerous in spring, and were often

numerous in summer when they had been few in spring. *A. fabae* were more numerous during most years than *M. persicae*, and *B. brassicae* usually scarce. Severe winters affected *M. persicae* more than the other two species.

7.10. Bunce, Maureen E. (1961). *Humicola stellatus* sp. nov., a thermophilic mould from hay. *Trans. Brit. mycol. Soc.*, **44**, 372–376.

Humicola stellatus sp. nov., a thermophilic mould found in mouldy hay from England and Wales, is described. *Monotospora lanuginosa* (Griff & Maubl.) Mason is transferred to *Humicola*.

7.11. Buxton, E. W. (Culbreth, W.) & (Esposito, R. G.) (1961). Separation of forms and physiologic races of pathogenic *Fusarium oxysporum*. Abstr. in *Phytopathology*, **51**, 575.

Two physiologic races of *Fusarium oxysporum* f. *cubense*, two of *F. oxysporum* f. *pisi* and one of *F. oxysporum* f. *lycopersici*, all of which appear identical in culture, were distinguished from each other by serological techniques. Gel-diffusion techniques gave more reliable results than agglutination. Haemagglutination, using the reactions between red cells of human blood group O and extracts of conidia of the fungi, also enabled distinctions to be made.

7.12. Gibbs, A. J. & (Tinsley, T. W.) (1961). Lucerne mosaic virus in Great Britain. *Plant Pathology*, **10**, 61–62.

Lucerne mosaic virus was found to be common in British crops of lucerne, and red and white clover. Most isolates of the virus from commercial lucerne crops gave only necrotic lesions on French bean plants, but 1·7% of the isolates infected this plant systemically. The symptoms caused by one " necrotic " isolate in test plants are described.

7.13. Gregory, P. H. (Longhurst, T. J.) & (Sreeramulu, T.) (1961). Dispersion and deposition of airborne *Lycopodium* and *Ganoderma* spores. *Ann. appl. Biol.*, **49**, 645–658.

Spores were liberated at 0·25 and 1·0 m. above grass. Airborne concentrations at twenty or more points in the spore cloud were measured with specially designed and calibrated miniature suction traps, operated off a portable vacuum system. Deposition in the downwind direction was measured on artificial surfaces on the ground. Measurements were made up to 10 m. from the source.

The observed increase in horizontal cross-wind standard deviation of the *Lycopodium* cloud agreed well with O. G. Sutton's theory, but was incompatible with that of W. Schmidt.

The coefficient of deposition, p, calculated from mean cloud concentration per c.c. and deposition to ground per cm.^{2}, as well as the velocity of deposition, v_g, varied with distance from source. Both p and v_g were larger for *Lycopodium* than for *Ganoderma*, and at the greater distances tested, v_g approximated to the expected terminal velocities of the particles in still air.

The total number (Q_0) of *Lycopodium* spores liberated in each experiment was known, and tentative estimates of the proportion deposited within the sampling area indicated that, under day-time winter conditions in England, the cloud lost not less than 13–24% of its load within 10 m. of the source.

7.14. Harrison, B. D. (1961). Identity of red currant spoon leaf virus. *Tijdschr. PlZiekt.*, **67**, 562–565.

Red currant spoon leaf virus, isolated from red currant in the Netherlands, is a strain of raspberry ringspot virus; it shares most of its antigenic groups with the " type " strain from Scottish raspberry, but causes distinctive symptoms in *Petunia hybrida*. It differs from tomato ringspot virus, obtained by Hildebrand (1942) from red currant in the U.S.A. Klesser's (1951) red currant ringspot virus is probably the same as red currant spoon-leaf virus.

7.15. Harrison, B. D., (Mowat, W. P.) & (Taylor, C. E.) (1961). Transmission of a strain of tomato black ring virus by *Longidorus elongatus* (Nematoda). *Virology*, **14**, 480–485.

Longidorus elongatus de Man was always found in soil from patches in raspberry and strawberry plantations where the plants were infected with the beet ringspot Scottish strain of tomato black ring virus but rarely elsewhere in the same plantations. *L. elongatus* hand-picked from virus-containing field soil transmitted the virus to sugar beet, turnip and spinach seedlings, but did so less often than might have been expected from the infectivity of the whole soil from which the nematodes came. Non-infective *L. elongatus* acquired and subsequently transmitted the virus from infected cucumber and potato plants. When hand-picked adult and larval *L. elongatus* were used separately, only larvae transmitted. Also, when infective soil was fractionated by sieving through meshes of successively smaller size, the infectivity of the fraction retained on each sieve, relative to the number of *L. elongatus* it contained, was greatest for samples containing the smallest larvae. A previously undescribed species of *Longidorus*, closely related to *L. elongatus*, was associated with an outbreak of the lettuce ringspot (English) strain of tomato black ring virus.

7.16. Harrison, B. D. & Winslow, R. D. (1961). Laboratory and field studies on the relation of arabis mosaic virus to its nematode vector *Xiphinema diversicaudatum* (Micoletzky). *Ann. appl. Biol.*, **49**, 621–633.

Xiphinema diversicaudatum is widely distributed in southern Britain, mainly in heavy soils, but also in the peat soil of the Fens and in medium-textured soils in the south-west. Patches of plants infected with arabis mosaic virus (AMV) in a range of crops including some, like celery and marrow, not before known to be hosts, coincide with patches of soil infested with *X. diversicaudatum*. Roots of some plants infested with the nematode carried small galls: not all such plants were infected with, or even susceptible to, AMV. Adult *X. diversicaudatum* transmitted AMV more readily than larvae, but none of 103 nematodes, transferred when moulting, infected healthy plants. *X. diversicaudatum* were still infective after 24 days in moist peat free from plants.

X. diversicaudatum is common in several districts in soil from old hedgerows, but not in the adjacent fields. Hedgerow trees seem to be hosts of the nematode, and at least one, elder, is also a host of AMV. In other districts plants with AMV occur in crops near to infested hedges or isolated trees, and on land taken into cultivation after being derelict. In the Tamar Valley, Devon, *X. diversicaudatum* is common in pastures; white clover in these often contains AMV. Planting such fields with strawberry leads to disease outbreaks.

A few *X. diversicaudatum* occur down to 3 feet in soil, but most are at 3–9 inches. At a site where arable land has reverted to woodland the nematodes have apparently spread from a hedge into the woodland at an average rate of 1 foot year over a period of 75 years. It is suggested that both *X. diversicaudatum* and AMV are common constituents of natural woodland in Britain and that their incidence has decreased since the advent of agriculture.

7.17. Hastie, A. C. (1962). Genetic recombination in the hop-wilt fungus *Verticillium albo-atrum*. *J. gen. Microbiol.*, **27**, 373–382.

Heterokaryons obtained between nutritional mutants of the imperfect fungus *Verticillium albo-atrum* were very unstable, and heterokaryotic hyphal tips growing out from mixed inocula were difficult to find. Heterokaryotic conidia were not detected, in spite of the fact that about 1% of the spores contained two or three nuclei. Heterozygous nuclei in uninucleate conidia from mixed cultures yielded recombinant phenotypes at a higher frequency than usually observed in the other imperfect fungi that have been studied genetically. With no easily applicable criterion of chromosome number, such as spore size, the interpretation of results is difficult, but the genetic recombination demonstrated here seems likely to be accomplished through a parasexual system. Nuclei heterozygous at some loci but homozygous at others were formed from nuclei heterozygous at four marked loci, and were detected by isolating second-

order segregants. These heterozygous segregants were presumably produced by mitotic recombination.

7.18. (Cockbain, A. J.) & Hastie, A. C. (1961). Susceptibility of the bed bug, *Cimex lectularius* Linnaeus, to *Aspergillus flavus* Link. *J. Insect Path.*, **3**, 95–97.

(For summary see below No. 10.16.)

7.19. Heathcote, G. D. & (Broadbent, L.) (1961). Local spread of potato leaf roll and Y viruses. *Eur. Potato J.*, **4**, 138–143.

In 1957 and 1959 potato tubers infected with either leaf roll or potato Y viruses at planting time were planted in pots which were sunk into the ridges of a crop of healthy potatoes for part of the season only. In 1957 both viruses spread to many neighbouring plants from "infectors" exposed during June, but not from those exposed later. In 1959 all spread again occurred before mid-July. There was no more spread from young "infectors" later in the season than from those of the same age as the crop, and the disease incidence in these plots did not differ significantly from those without "infectors". There was negligible spread of virus from plants infected early in the same season.

Aphids were few during late summer in both years, but the experiments confirmed that most spread within the crop occurs early at Rothamsted, and that insecticidal treatments aimed at decreasing virus spread should begin early; continuing them after mid-July is often less important.

7.20. Hirst, J. M., (Le Riche, H. H. & Bascomb, C. L.). (1961). Copper accumulation in the soils of apple orchards near Wisbech. *Plant Path.*, **10**, 105–108.

During epidemiological studies of apple scab, *Venturia inaequalis* (Cooke) Wint., in the Wisbech area of Cambridgeshire, soils of some orchards on one holding were found to be atypical and unusually rich in copper. This paper compares the soils of two atypical orchards (AB and AR) with typical soils from five grassed and two arable orchards on other holdings, all within 5 miles of Wisbech. Orchard AR had been used for an experiment to test what effect different amounts of the sodium salt of dinitro-ortho-cresol had on the number of ascospores liberated from leaves which had overwintered on the ground. The soil of these plots was later sampled to find whether the treatments had affected the earthworm population, but the results were inconclusive, as very few worms were found in treated or untreated plots. During sampling, J. W. Stephenson noticed that the soil profile was atypical of grass-covered apple orchards in the area, and further work suggested that plant-protective chemicals, particularly Bordeaux mixture, may have modified the soil.

7.21. Hirst, J. M. & Stedman, O. J. (1961). The epidemiology of *Phytophthora infestans*. III. Spraying trials 1952–1958. *Plant Path.*, **11**, 7–13.

The yield of Majestic potatoes was increased significantly in only 2 of 7 years by applying two copper oxychloride sprays, whether or not the haulms were killed by sulphuric acid. Rows along which tractors passed while spraying yielded on average 0·7 tons/acre less than undamaged rows. Up to 20% of King Edward tubers were infected in 1957, but at no time were more than 2·5% of Majestic tubers blighted.

7.22. Hirst, J. M. & Stedman, O. J. (1961). The epidemiology of apple scab (*Venturia inaequalis* (Cke.) Wint.). I. Frequency of airborne spores in orchards. *Ann. appl. Biol.*, **49**, 290–305.

The number of ascospores caught by automatic volumetric spore traps differed widely in six orchards where the air was sampled in some or all of the years 1955–59. To compare amounts of inoculum in different orchards the total catch in each was expressed as the "relative ascospore dose". The reason for the much smaller doses in the later years is uncertain. The results confirmed earlier work on the phenology of ascospore liberation and stressed the practical need to decrease their number as much as possible.

Because conidia have previously been trapped almost only on wet and windy days, they have been considered to be rarely air-dispersed. Our apparatus, which efficiently traps dry conidia but catches water-borne ones only when in very small droplets, caught airborne conidia in all orchards where they operated during summer. Traps among heavily infected, unsprayed trees caught most conidia around noon on warm dry days, and the highest concentration measured exceeded 1,300/m.^{3} of air.

7.23. Kassanis, B. (1961). The transmission of potato aucuba mosaic virus by aphids from plants also infected by potato viruses A or Y. *Virology*, **13**, 93–97.

None of twelve strains of potato aucuba mosaic virus (PAMV) tested was transmitted by the aphid *Myzus persicae* Sulz. from plants infected with PAMV alone. Strains differed in the ease with which they were transmitted from plants which were also infected with either potato virus A or Y. Some were only occasionally transmitted, and others readily—some more readily from plants infected with Y than with A, and others only from plants infected with Y.

Infection with either virus Y or A increased the concentration of PAMV, more so by Y than by A. The transmissibility of PAMV was not correlated with its concentration in expressed sap. The concentration of PAMV differed at different seasons, and in summer was too low to be detected serologically in plants also infected with virus A.

7.24. Kassanis, B. (1961). Potato paracrinkle virus. *Eur. Potato J.*, **4**, 13–24.

Potato paracrinkle virus and potato virus S share only a few antigenic groups and do not protect plants against one another. All plants from commercial stocks of the variety King Edward tested were virus-infected, some by potato paracrinkle virus alone, some by both viruses and one by potato virus S only.

Infected King Edward plants are not symptomless, as they were long thought to be; in comparison with plants of a virus-free clone, derived from an apical meristem, they are less vigorous, and their leaves are paler and more ruffled. The use of virus-free Arran Victory plants derived from apical meristems showed that severe paracrinkle symptoms can be caused by potato paracrinkle virus without potato virus S being present. Potato paracrinkle virus occurs in stocks of King Edward in strains of different virulence towards Arran Victory. Some of these strains are transmitted by *Myzus persicae*.

The name leaf-rolling mosaic is proposed for a group of serologically related viruses, divided into three sero-types.

7.25. Kassanis, B. & Nixon, H. L. (1961). Activation of one tobacco necrosis virus by another. *J. gen. Microbiol.*, **25**, 459–471.

Preparations of the Rothamsted culture of tobacco necrosis virus always gave two and usually three zones when centrifuged in sucrose density gradients. The top zone consisted of polyhedral particles with a sedimentation constant of 50S, the middle zone of larger polyhedral particles with 116S and the bottom zone, when present, consisted of the 50S particles aggregated in groups of 12. Neither the small particles (50S) nor their aggregates were infective when inoculated either to tobacco or French bean plants, but they became so when inoculated together with the large particles (116S). The small and large particles are serologically unrelated, and seem to be different viruses, one of which depends on the other for some process that allows it to multiply to detectable amounts.

The Rothamsted culture produces local lesions of different sizes in French bean. Virus isolated from single large lesions and passed through a succession of single lesions gave, when bulked in tobacco, preparations containing up to 500 large to 1 small particle. Evidence is given which suggests that the few small particles were acquired as contaminants when the virus was bulked in tobacco, and it seems probable that small particles would not be produced in leaves infected only with the large particles. Virus obtained from small lesions when bulked gave preparations containing particles of both sizes, with ratios of large to small particles up to 1 : 10. Inocula of large particles produced only

large lesions, whereas mixed inocula produced large and small lesions, in proportions which depended on the ratio of the two kinds of particles in the inoculum. Two different tobacco necrosis viruses activated the small particles, but tobacco mosaic and some other viruses did not.

Particles of the two activating viruses differed in size and in their stability when negatively stained in phosphotungstate. When fixed and negatively stained they appeared to be angular, but much less so than when shadowed. Small particles tended to pack in regular arrays, and one type of packing suggested that they have a fivefold axis of symmetry.

7.26. KLECZKOWSKI, A. (1961). Serological behaviour of tobacco mosaic virus and of its protein fragments. *Immunology*, **4**, 130–141.

The protein obtained when tobacco mosaic virus is disrupted with alkali is antigenically heterogeneous, whereas the intact virus is homogeneous. Aggregating the protein by acidification makes it again antigenically homogeneous. In comparable conditions, antibody antigen ratio is considerably higher in precipitates formed by the protein than in those formed by the virus. Aggregating the protein restores the ratio to that given by the original virus.

Electron-microscopic examination shows that in extreme antibody excess each virus particle is covered with a layer of antibody molecules. In these conditions, therefore, individual antibody molecules seem not to bridge directly between different virus particles, but they may do so in the zone of equivalence.

7.27. KLECZKOWSKI, A. & (KAMMEN, A. VAN). (1961.) Protection from proteolysis by aggregating the protein isolated from tobacco mosaic virus. *Biochim. biophys. Acta*, **53**, 181–185.

Disaggregated protein isolated from tobacco mosaic virus is hydrolysed by chymotrypsin and papain, but when aggregated into rod-shaped particles the protein, like the original virus, resists attack by the enzymes. This suggests that only some walls of the protein sub-unit are susceptible to proteolysis, and these walls become inaccessible to the enzymes when the protein aggregates in the orderly fashion required to form rods.

7.28. LAPWOOD, D. H. (1961). Potato haulm resistance to *Phytophthora infestans*. I. Field assessment of resistance. *Ann. appl. Biol.*, **49**, 140–151.

The resistance to potato blight (*Phytophthora infestans* (Mont.) de Bary) of the haulms of four potato varieties, Up-to-Date (UD), King Edward (KE), Majestic (MJ) and Arran Viking (AV), was assessed in the field from 1956 to 1959. Although these varieties are reputed to differ appreciably in resistance, the differences measured were smaller than expected and significant in only two seasons. They were shown better by measurements on individual leaves than by assessing effects on whole plots. The greater resistance of AV and MJ, compared with UD and KE, was correlated with a slower increase of blight at the start of an attack rather than with differences in the rate of haulm destruction when the attack was well advanced. However, there was some evidence that leaves of KE died most rapidly and leaves of AV most slowly after infection.

7.29. LAPWOOD, D. H. (1961). Potato haulm resistance to *Phytophthora infestans*. II. Lesion production and sporulation. *Ann. appl. Biol.*, **49**, 316–330.

The slower increase of blight (*Phytophthora infestans* (Mont.) de Bary) in field plots of Majestic (MJ) and Arran Viking (AV) than of Up-to-Date (UD) and King Edward (KE) potatoes seems more closely related to the production of fewer spores than to greater resistance of leaves to infection.

Sporing was decreased, not by differences in generation time, but because fewer spores were produced per lesion on MJ and AV, especially when lesions were small (young). Infected cells of AV died more rapidly than cells of UD and KE, and so left a smaller area of sporing tissue in young lesions. Although the fungus advanced at much the same rate in leaves of the four varieties, sporing annuli were narrower on older (larger) lesions on AV unless high relative

humidity persisted continuously. Sporangiophores and sporangia were formed more rapidly on UD than AV when non-sporing lesions were transferred to high humidity. The ecoclimate of a crop of UD did not increase the sporulation of infected leaves of AV exposed within it, but sporulation was slightly decreased when infected UD leaves were exposed in a crop of AV. Generally KE behaved like UD, with MJ intermediate between these and AV.

The lower leaf-surface was more susceptible to infection than the upper. Differences in susceptibility of lamina between varieties were inconsistent. MJ and AV were more resistant than UD and KE when inoculated in leaf axils.

7.30. Lapwood, D. H. (1961). Potato haulm resistance to *Phytophthora infestans*. III. Lesion distribution and leaf destruction. *Ann. appl. Biol.*, **49**, 704–716.

Reasons were sought for the difference in haulm resistance to potato blight (*Phytophthora infestans* (Mont.) de Bary) of four potato varieties. Up-to-Date produced more foliage than King Edward, Majestic and Arran Viking, and its denser canopy prolonged periods of high relative humidities and lowered midday temperatures by a few degrees. When field conditions favoured infection the fungus spread in all varieties, but most extensively in King Edward and least in Arran Viking. Infections developed first, mainly in the lower canopy, then the middle and finally in the upper canopy, with lesions on leaves and leaflets distributed similarly on all varieties.

The fungus advanced at the same rate in leaf laminae of all the varieties, but not in petioles, which were girdled more rapidly in Up-to-Date and King Edward than in the other two, and consequently led to the collapse of more leaves.

Majestic and Arran Viking are more resistant than Up-to-Date and King Edward in the field, because their leaves are infected more slowly early in the blight attack and die more slowly after infection.

7.31. Lapwood, D. H. (1961). Laboratory assessments of the susceptibility of potato haulm to blight (*Phytophthora infestans*). *Eur. Potato J.*, **4**, 117–128.

The reactions to *Phytophthora infestans* of the haulm of forty-three potato varieties of different maturity were compared with that of the variety Majestic. Laboratory tests assessed relative resistance by five criteria: (1) ease of infection of leaf lamina; (2) susceptibility of leaf tissue to fungal advance; (3) spores produced per area of infected leaf; (4) susceptibility of stem; and (5) susceptibility of leaf petiole when leaf axils were inoculated. Susceptibility of resistance for each criterion was based on a significant difference ($P = 0{\cdot}05$) between the test variety mean and Majestic. Early varieties were more susceptible than Majestic, most by all criteria; different maincrop varieties reacted differently, and resistance usually showed as a decrease in number of spores produced; most late-maturing varieties were more resistant than Majestic, the fungus advanced more slowly and produced fewer spores.

7.32. Lapwood, D. H. (1961). Sporulation of blight on potato tubers within ridges. *Plant Path.*, **10**, 40.

Potato blight was found sporulating from the lenticels and sometimes eyes of infected tubers, underground, within the ridges, first on Ulster Ensign and later on Up-to-Date, King Edward and Arran Banner. Sporing tubers were readily found when the ridge was drying after rain, but were difficult to find during or immediately after further rain.

7.33. Lapwood, D. H. (with McKee, R. K.) (1961). Reaction of tubers of R-gene potato clones to inoculation with specialised races of *Phytophthora infestans*. *Eur. Potato. J.*, **4**, 3–13.

Tubers of 46 R-gene potato clones were inoculated with races of *Phytophthora infestans*, which either: (1) caused a hypersensitive reaction on the leaves of the clone, or (2) could infect and spread in the leaves. The gene R_1 conferred comparable hypersensitivity to tubers and leaves, whereas genes R_2, R_3 and R_4 often did not. Races giving a hypersensitive reaction in the leaves of R_2, R_3 and R_4 clones grew in the tubers, but more slowly than in clones without these genes.

Tubers of most clones were highly susceptible (often more so than the clone King Edward) to races of the fungus that spread in their leaves. Orion and Reaal were two of the few clones whose tubers resisted infection by races able to invade their leaves.

7.34. Miczynski, K. A. (1960). An attempt to inhibit the multiplication of tobacco mosaic virus in tissue culture by its antiserum. *Ann. appl. Biol.*, **48**, 739–741.

Extracts from tobacco tissue cultures infected with tobacco mosaic virus grown in medium containing antiserum to the virus had only one-half to one-sixteenth as much virus as extracts from tissues grown in medium without the antiserum. When tissues grown with antiserum were thoroughly washed before they were extracted their extracts contained as much virus as extracts of tissues grown without antiserum. The antiserum did not affect virus multiplication, but antibodies in the tissues may have precipitated virus either in the cells or when the tissues were macerated.

7.35. (Weir, A. H.,) Nixon, H. L. & Woods, R. D. (1962). The measurement of dispersed clay flakes with the electron microscope. In *Clays and Clay Minerals*. London: Pergamon Press pp. 419–423.

(For summary see No. 3.5. above.)

Nematology Department

Book

8.1. Shepherd, A. M. (1962). *The Emergence of Larvae from Cysts in the Genus Heterodera*. Farnham Royal: Commonwealth Agricultural Bureaux, 87 pp.

General Papers

8.2. Doncaster, C. C. (1962). Natürliche wirtschaftlich wichtiger Schadnematoden. *Umschau*, **62**.

8.3. Goodey, J. B. (1962). Taxonomic relatedness in Nematology. *Ann. appl. Biol.*, **50**, 175–177.

8.4. Jones, F. G. W. (1962). The nematode problem. *In: Proceedings of the British Insecticides and Fungicides Conference*, Brighton, 1961.

8.5. Peachey, J. E. (1962). Investigations on nematicidal activity of and crop responses to chemical soil sterilants. In *Proceedings of the British Insecticides and Fungicides Conference*, Brighton, 1961.

8.6. Shepherd, A. M. (1961). Nematode-trapping fungi in Danish agricultural soils. *Horticultura*, **15**, 94–96.

Research Papers

8.7.* Blake, C. D. (1961). Root rot of bananas caused by *Radopholus similis* (Cobb) and its control. *Nematologica*, **6**, 295–310.

Radopholus similis causes a serious root-rot of bananas (*Musa cavendishii*) in New South Wales. The histopathology of root lesions and the role of the fungi *Fusarium oxysporum* and *Rhizoctonia solani* as secondary colonists are described. Reproduction on *M. acuminata banksii* and *Saccharum officinarum*, but not on *Citrus* spp. showed the " banana " race of *R. similis* was responsible. Root rot was controlled for 6 months by preplant soil fumigation with the

* Work done in New South Wales.

nematicides methyl bromide, " D.D ", " Vapam " or " Nemagon ", but re-infestation occurred after 11 months. *R. simulis* was not found in virgin soils, but was introduced by planting infested sets. Sets less than 13 cm. diameter were disinfested by immersion in water at 55° for 20 minutes without abnormal set losses. Chemical dipping failed to disinfest them. A hot-water bath and a method for the bulk treatment of sets are described.

8.8. Blake, C. D. (1961). Importance of osmotic potential as a component of the total potential of the soil water on the movement of nematodes. *Nature, Lond.*, **192**, 144–145.

Larvae of *Ditylenchus dipsaci* moved at similar speeds through sands of particle size 250–500 μ wetted with distilled water or urea solution. Movement in both moisture regimes was related to the moisture characteristic and was fastest when the pores of the sand were draining. Movement in sand depends on the forces holding the soil water in the pore spaces and is independent of the osmotic pressure of the soil water, until the solute concentration is high enough to cause incipient plasmolysis of the nematodes. The length of larvae suspended in urea solutions decreased as the osmotic pressure of the solutions increased. Shrinking was greatest in the range 0·001–1*M* concentration and the larvae reached their minimum lengths at approximately pF = 4·1. The solute concentration required to kill nematodes is about the same as that which causes permanent wilting of plants, and so it is unlikely that soil additives such as sugars which act only osmotically would be useful nematicides.

8.9. Clark, W. C. (1962). *Amphorostoma saccatum* n. gen. et sp. Family Leptonchidae (Enoplida, Nematoda). *Nematologica*, **7**, 193–196.

A new genus *Amphorostoma* is proposed within the family Lectonchidae for nematodes with a flask-shaped, sclerotised stomatal lining, and large amphids with sinuous apertures. In the only known species the female has a single, outstretched, anterior ovary, with a large post-vulval sac. The type, and only species, *Amphorostoma saccatum* n. sp. is described.

8.10. Clark, W. C. (1962). Evolution within the family Mononchidae (Enoplida, Nematoda). *Nematologica*, **7**, 251–255.

The course of evolution within the family Mononchidae is deduced from morphology and ontogeny as far as this is known. Early in evolution the Mononchidae divided into two groups, one with a tuberculate oesophago-intestinal junction and a broad base to the sclerotised stoma and the other non-tuberculate and with a narrow stoma base. Further evolution within both lines was smaller size and eventual loss of the subventral teeth. In the non-tuberculate group subventral denticles appeared on the stoma walls, but in most genera these have become less and tended to fuse to form subventral ridges (e.g. *Prionchulus*), which in most *Mononchus* spp. have been lost entirely.

8.11. Clark, W. C. (1962). The systematic position of the Alaimidae and the Diphtherophoroidae (Enoplida, Nematoda). *Nematologica*, **7**.

An earlier classification of the order Enoplida is amended by transferring the Diphtherophoroidea from the sub-order Dorylaimina to the sub-order Alaimina. The change is based primarily on the occurrence of: (1) well-developed excretory pores, and (2) males with one testis and non-muscular, non-differentiated vasa deferentia, both features characteristic of the Alaimidae and the Diphtherophoroidea but not of the Dorylaimina, to which the Diphtherophoroidea were previously referred.

8.12. Doncaster, C. C. & Hooper, J. D. (1961). Nematodes attacked by Protozoa and Tardigrades. *Nematologica*, **6**, 333–335.

Nematodes in a water extract from turf were ingested by a protozoon, *Urostyla* sp. The nematodes eventually escaped from ingestion without apparently being harmed, but sometimes the *Urostyla* were damaged. Tardigrades, *Macrobiotus* sp., readily attacked and fed on nematodes in a water extract from soil, eventually killing them.

8.13. (Harrison, B. D.) & Winslow, R. D. (1961). Laboratory and field studies on the relation of arabis mosaic virus to its nematode vector *Xiphinema diversicaudatum* (Micoletzky). *Ann. appl. Biol.*, **49**, 621–633.

(For summary see above No. 7.16.)

8.14. Hesling, J. J., Pawelska, K. & Shepherd, A. M. (1960). The response of potato root eelworm *Heterodera rostochiensis* Wollenweber and beet eelworm *H. schachtii* Schmidt to root diffusates of some grasses, cereals and of *Tagetes minuta*. *Nematologica*, **6**, 207–213.

Three experiments failed to produce evidence that root diffusates from cereals and grasses stimulate eggs of *Heterodera rostochiensis* to hatch *in vitro*. Diffusate from *Tagetes minuta*, tested in one experiment, neither stimulated nor inhibited hatch. Diffusate from cereals, grasses and *Tagetes minuta* differed very little in effect from soil water. Diffusate from rye and perennial ryegrass did not stimulate cysts of *H. schachtii*. The experiment emphasised the need to test diffusates over a range of dilutions.

8.15. Hooper, D. J. (1961). A redescription of *Longidorus elongatus* (de Man, 1876) Thorne & Swanger, 1936. (Nematoda, Dorylaimidae) and descriptions of five new species of *Longidorus* from Great Britain. *Nematologica*, **6**, 237–257.

Longidorus elongatus (De Man, 1876) Thorne & Swanger, 1936, is redescribed from specimens obtained from the type locality. *L. elongatus* is characterised by its attenuated body, continuous to slightly expanded lip region flattened anteriorly, dorsally convex, roundly conoid tail as long or slightly longer than the anal-body-width, and stylet 85–95 μ long. Measurements and descriptions are also given of specimens, including males and larvae, from Britain. *L. leptocephalus* n. sp. and *L. attenatus* n. sp. differ from *L. elongatus* in that the former is smaller with a narrower lip region, shorter stylet and more pointed tail; the latter has a more attenuated body, greatly expanded lip region, more pointedly conoid tail and a shorter stylet. *L. goodeyi* n. sp. and *L. caespiticola* n. sp. are slightly longer and appear more robust than *L. elongatus*. *L. goodeyi* has large, asymmetrically bilobed amphids and a roundly flattened lip region; *L. caespiticola* has a roundly conoid lip region and large pouch-shaped amphids. Both of these species have blunt conoid to round tails about an anal-body-width long. *L. macrosoma* n. sp. is recognised by its size, 8–10 mm., continuous truncate lip region and short tail. Measurements of larval stages and illustrations of their tails are given for each species.

8.16. Hooper, D. J. (1961). A method for attaching the funnel to the flask for use in the Seinhorst two-Erlenmeyer-flask soil extraction technique. *Nematologica*, **6**, 336.

Flasks for use in the two-Erlenmeyer extraction technique have a rubber collar of cycle inner tube fitted around the neck so as to leave a small inwardly projecting overlap. Three rubber bands are held in place by a ring of copper wire round the flask neck. A plastic funnel, cut down to fit just inside the flask rim, is also fitted with an overlapping rubber ring. The funnel is held in place on the flask by stretching the rubber bands on the wire around the flask neck over screw heads fixed in a collar round the stem of the funnel.

8.17. Hooper, D. J. (1961). Effects of a nematode on the growth of mushroom mycelium. *Nature, Lond.*, **193**, 496–497.

Aphelenchus avenae from mushroom compost fed on mushroom hyphae on agar plates and reproduced rapidly. When added to tubes of compost with growing mushroom mycelium, *A. avenae* also reproduced rapidly and the mycelium was destroyed.

8.18. Hooper, D. J. (1962). Observations on *Aphelenchoides limberi* Steiner, 1936 from mushroom compost. *Nematologica*, **7**, 216–218.

Aphelenchoides limberi Steiner 1936 from mushroom compost readily feeds on mushroom hyphae on agar plates, reproduces rapidly and breaks down the

mycelium. It also reproduces on the fungus *Botrytis cinerea*. Appearance and measurements of the specimens from mushroom closely agree with Steiner's original description. The shape of the tail terminus is very variable. No males occurred in the cultures.

8.19. Jones, F. G. W. (1961). The potato-root eelworm, *Heterodera rostochiensis* Woll. in India. *Curr. Sci.*, **30**, 187.

Potato-root eelworm is reported in India for the first time at Ootacamund in the Nilgiris about 7,000 feet above sea-level.

8.20. Krusberg, L. R. (1961). Studies in the culturing and parasitism of plant-parasitic nematodes, in particular *Ditylenchus dipsaci* and *Aphelenchoides ritzemabosi* on alfalfa tissues. *Nematologica*, **6**, 181–200.

Ditylenchus dipsaci and *Aphelenchoides ritzemabosi* reproduced rapidly on alfalfa callus tissue grown on a nutrient agar medium containing 2 : 4-dichlorophenoxyacetic acid (2 : 4-D). Cultures inoculated with fifty nematodes and kept at 22° contained 40,000–80,000 individuals after 2 months. *Pratylenchus zeae* and *P. penetrans* reproduced well and *Tylenchorhynchus capitatus* and *Hoplolaimus coronatus* slowly on callus. Four of these species were maintained alive in such cultures for 2 years without subcultures.

The histopathology of *D. dipsaci* and *A. ritzemabosi* on alfalfa seedlings grown in soil, seedlings grown aseptically on nutrient agar medium and callus tissue grown aseptically on nutrient agar medium plus 2 : 4-D was examined. *D. dipsaci* penetrated directly through the epidermis in the bases of cotyledons of alfalfa seedlings in soil and formed cavities in cortical parenchyma within 12 hours of inoculation. Infected stems were noticeably swollen at 36 hours after inoculation. Many parenchyma cells were destroyed and others distorted in galled tissue, particularly in young, actively growing shoots. Only cavities were formed in roots of infected seedlings growing on agar medium with no galling; shoot galls were identical with those of infected plants in soil. *A. ritzemabosi* fed primarily as an ectoparasite on shoots of alfalfa seedlings, inhibiting apical growth and resulting in severely stunted and malformed plants, but a few lived in the mesophyll of cotyledons. Both nematode species fed and reproduced in the loose parenchyma of callus tissue, with the nematodes moving from the callus to the agar and test-tube walls in older cultures.

Sugars, organic acids and amino acids were examined in alfalfa tissues as used in the histological studies. Neither nematodes nor the conditions under which plants or tissues were grown affected qualitatively the sugars or organic acids, and affected only two of the twenty-three major amino acids identified. Gall tissue of plants infected *D. dipsaci*, and all callus tissue samples contained free tryptophane, whereas healthy plants or those parasitised by *A. ritzemabosi* did not. Tissue parasitised by *A. ritzemabosi* contained abundant free tyrosine, whereas nematode-free or *D. dipsaci*-infected tissues contained little or none.

8.21. (Luc, M.) & Goodey, J. B. (1962). *Hirschmannia* n.g. differentiated from *Radopholus* Thorne, 1949 (Nematoda: Tylenchoidae). *Nematologica*, **7**, 197–202.

Re-examination of a specimen of *Tylenchorhynchus spinicaudatus* Sch. Stek., 1944 showed it to be conspecific with *Radopholus lawabri* Luc, 1957. This is made the type of *Hirschmannia* n.g. which also contains *H. gracilis* n. comb. and *H. oryzae* n. comb. The lectotype of *H. spinicaudata* is redescribed and *Radopholus* redefined.

8.22. Wallace, H. R. (1961). The orientation of *Ditylenchus dipsaci* to physical stimuli. *Nematologica*, **6**, 222–236.

In a temperature gradient of 2°–30° over 15 cm., *D. dipsaci* aggregates at about 10°. In a moisture gradient the nematodes aggregate at the end with a high moisture content and in a particle size gradient they collect in the fine particles at one end of the gradient. Light, gravity and water percolation do not affect the orientation of *D. dipsaci*, although passive directional movement may occur with the last two stimuli.

8.23. Wallace, H. R. (1962). Observations on the behaviour of *Ditylenchus dipsaci* in soil. *Nematologica*, **7**, 91–101.

The vertical distribution of *D. dipsaci* in soil in an infested oat plot resembled that of other nematodes except that, after rain, the numbers of *D. dipsaci* at the surface increased greatly. *D. dipsaci* migrated to the surface of the soil and could survive drying in an atmosphere of 50% relative humidity for 34 days, equivalent to a soil moisture tension of pF 6 in a dry soil. When infested plants were wetted many *D. dipsaci* emerged. This nematode moved farther in a sandy loam than in a clay soil, but oat seedlings were invaded at similar rates in a clay loam and a sandy loam.

Insecticides and Fungicides Department

General Papers

9.1. (Crombie, L.) & Elliott, M. (1961). Chemistry of the natural pyrethrins. *Fortschr. Chem. org. Naturst.*, **19**, 120.

9.2. McIntosh, A. H. (1961). Physical conditions affecting *in vitro* fungistatic action on conidia of *Botrytis fabae* Sardiña. S.C.I. Monogr. No. 15, p. 37.

9.3. Potter, C. (1961). The future of chemical control of insects. *Ann. appl. Biol.*, **49**, 391–402.

9.4. Potter, C. & Bardner, R. (1961). The Protection of Seed: Modern methods in use both before and after sowing. *Article 7449, Central Office of Information, London.*

9.5. Way, M. J. (1961). Crop losses by insects and the problem of control. *Proc. Nutr. Soc.*, **20**, 5–11.

Research Papers

9.6. Elliott, M. (1961). La distillation moléculaire des Pyréthrines. *Feuilles d'Information du Comité Français pour l'Etude des Applications des Pyréthrines*, No. 5, 6.

The problems of separating the four colourless high-boiling unstable insecticidal constituents of pyrethrum extract from highly coloured, inert contaminants are discussed.

By the process of molecular distillation a 25% extract gives a pale-coloured distillate containing 65% of pyrethrins, a low-boiling forerun with 2–3% of pyrethrins and leaving undistilled a residue with only low biological activity.

Physical and chemical analyses show that there is little if any degradation or thermal isomerisation under the conditions used, and bioassays detect no loss of insecticidal activity in the process.

9.7. Elliott, M. & Jeffs, K. A. (1961). A synthesis of calythrone. *Proc. chem. Soc., Lond.*, 374.

Calythrone, 3, 4-dimethyl-2-isovalerylcyclopent-4-ene-1, 3-dione, found in *Calythrix tetragona* Lab., was synthesised by condensation of dimethyl dimethylmaleate with isobutyl methyl ketone in the presence of sodium hydride. It has insecticidal activity.

9.8. (Innes, N. L.) & Last, F. T. (1961). Cotton disease symptoms caused by different concentrations of *Xanthomonas malvacearum*. *Emp. Cott. Gr. Rev.*, **38**, No. 1, 27–29.

Increasing concentrations of inoculum increased the size and severity of individual lesions. Differences were larger on susceptible cotton varieties than on resistant types.

9.9. Last, F. T. 1961. Direct and residual effects of *Striga* control treatments on sorghum yields. *Trop. Agric., Trin.*, **38**, No. 1, 49–56.

Sorghum crops were grown in 1958 to assess the residual effects of treatments applied in 1957 to control *Striga hermonthica*. Trap cropping with Sudan grass for 3 weeks, but not for 3, significantly decreased the incidence of *S. hermonthica* and increased grain yields of sorghum planted in both 1957 and 1958 by 500 lb./acre; in the first season straw yields were decreased.

Spraying, two to three weeks after planting, with 0·8–1·6 lb. acre of the sodium salt of 2:4-dichlorophenoxyacetic acid delayed the emergence of *S. hermonthica* and increased sorghum grain and straw yields in 1957, but had no residual effect in 1958.

Giving 80 lb. nitrogen and 40 lb. phosphorus pentoxide per acre in 1957 increased yields of sorghum in 1957 and 1958. The increases in the first season varied with the dates of application: nitrogen and phosphorus given at sowing, and 3, 6, and 9 weeks later, increased grain yields from 905 to 3,510, 3,790, 3,000 and 1,440 lb./acre respectively. In 1958 the residual effect, an increase from 2,150 to 3,210 lb./acre of grain, was the same for all dates of application. The incidence of *S. hermonthica* was not significantly affected by fertilisers in 1957, but less developed in 1958 where nitrogen and phosphorus were given in 1957.

9.10. Last, F. T. & Nour, M. A. (1961). Cultivation of *Vicia faba* L. in Northern Sudan. *Emp. J. exp. Agric.*, **29**, No. 113, 60–72.

Winter-sown broad beans in the north of the Sudan became heavily infested with *Leveillula taurica*, *Erysiphe umbelliferarum* and *E. polygoni*. Spraying with lime sulphur, two or three times per season, decreased the incidence of these powdery mildews, and increased yields by 23%. Sulphur sprays were as effective as lime sulphur, but "Karathane" did not significantly increase yields.

Spraying increased the yields most with beans sown at the optimal date. Varying the concentrations of lime sulphur from 1 in 80 to 1 in 120 v/v, and increasing the frequency of spraying from every third week to weekly did not affect yields.

At Shambat the highest yields, in two of three experiments, were given by crops sown at the beginning of November—earlier sowings are usually severely infested by insects. At Zeidab, 170 miles north of Shambat, high yields were given by crops sown from mid-October to early November. The yields of delayed plantings were much lower.

Nitrogen fertiliser significantly increased mean yields. The increases were twice as large on sprayed as on unsprayed crops, and were smaller on crops sown at the optimum time than on those sown on other dates. Phosphorus and potassium separately did not affect yields, but together they increased them as much as nitrogen.

At Shambat doubling the usual seed-rate of the local variety of beans increased yields by 48%. On introduced varieties, which yielded less, the effect was smaller.

9.11. Lord, K. A. (1961). The partial purification and properties of a cholinesterase from *Blatella germanica* L. *Biochem. J.*, **78**, 483–490.

A purified preparation of cholinesterase was obtained from *Blatella germanica*. The purification was 40-fold and the yield 32%. The enzyme has a high affinity for acetylcholine and is inhibited by high concentrations of this and analogous esters. Various salts activate the enzyme at high concentrations of acetylcholine, and under some circumstances inhibit at low substrate concentrations. The enzyme hydrolyses phenyl and triglyceryl esters as well as choline esters. Esters of acetic acid and propionic acid are hydrolysed much more rapidly than those of butyric acid. The enzyme showed optimum activity to acetylcholine and the acetyl and propionyl esters of phenol over a wide pH range. The properties of the enzyme are characteristic of the type of cholinesterases frequently associated with nervous tissues, and are compared with those reported for cholinesterases from insect and other sources.

9.12. Lord, K. A. & Solly, S. R. B. (1961). Changes in the amino acid content of house flies after organophosphorus poisoning. *Chem. & Ind.*, 1359–1360.

House flies contain some free amino acids, the relative amounts of which may be specific for different strains of insects. When poisoned with organophosphorus insecticides the amounts of these amino acids change. The most obvious effect is a decrease in the free α-alanine. The changes observed seem to be specific for organophosphorus poisoning.

9.13. Lord, K. A. & (Rasmuson, B.) (1961). Phospholipid content in different strains of *Drosophila melanogaster* and the tentative relation to resistance to organophosphorus compounds. *K. LantbHögsk. Ann.*, **27**, 343–350.

This was a preliminary investigation using two strains of *D. melanogaster*, one susceptible to, the other resistant to, organophosphorus insecticides. The phospholipids were extracted in a 2:1 chloroform–methanol mixture, then purified and partially separated by absorption on and elution from silicic acid or alumina. The phosphorus and nitrogen contents of the fractions were assayed and showed that the two strains differed in phospholipids.

9.14. McIntosh, A. H. (1961). Effects of time and temperature on the fungistatic action of mercury-containing and other compounds on conidia of *Botrytis fabae* Sardiña. *Ann. appl. Biol.*, **49**, 433–444.

The *in vitro* fungistatic action of nineteen compounds was measured on conidia of two strains of *Botrytis fabae* Sardiña in slide-germination tests, at two or three incubation temperatures in the range 10°–25° C.; the effects were assessed at intervals up to 14 days from the start of each test.

In general, the ED50's increased as incubation time passed, finally approaching or reaching steady values. With each compound, an increase in incubation temperature increased the speed of action (i.e., decreased the time taken for the ED50 to reach a steady value), and increased the ultimate toxicity. Temperature coefficients were calculated as ratios of ED50's and were "positive" or "negative" according to whether the toxic action was greater or less at the higher temperature.

The conidia of the two strains of *B. fabae* behaved similarly, but the temperature coefficients were larger with one strain (A) than the other (B).

Mercuric cyanide, chloride, bromide, acetate and thiocyanate gave positive coefficients which increased in size as incubation time passed. In these tests, which lasted for only 3 days, the largest 10:25° C. coefficient (+35) was given by the cyanide after 3 days (strain A); the corresponding figures for the chloride and bromide were +10·5 and +6·0. Phenyl mercury acetate, methyl mercury nitrile, silver nitrate, copper sulphate, 8-hydroxyquinoline, acetamide, *p*-nitrophenol, 2:4-dinitrophenol and pentachlorophenol gave coefficients which were usually small and positive (about +1·3), and changed only slightly in size as incubation time passed. *t*-Butyl alcohol, pyridine, 3-picoline, phenol and *p*-chlorophenol gave coefficients which changed from negative (−3·9 to −1·5) to positive (+1·3 to +3·2) after 2–7 days (strain B).

There was little evidence that spores are more resistant to fungicides at their optimum temperature for germination, i.e., the temperature at which maximum germination is reached soonest (15–20° C. for *B. fabae*).

Mercuric cyanide, chloride and bromide, which are scarcely ionised in aqueous solution, also resembled non-electrolytes in that the sizes of their positive temperature coefficients were inversely related to their solvent: water partition coefficients, i.e., the temperature coefficients increased with decrease in the presumed rates at which lipoid membranes are penetrated by diffusion. This correlation did not extend to other compounds.

9.15. Molloy, Frances M. (1961). The histochemistry of the cholinesterases in the central nervous system of susceptible and resistant strains of the house fly, *Musca domestica* L., in relation to diazinon poisoning. *Bull. ent. Res.*, **52**, 667–681.

Inhibition of cholinesterase in the central nervous system of *M. domestica* after poisoning with diazinon is confined to certain parts of the ganglia; other

parts remain unaffected even after death. Total inhibition is rarely seen. This indicates that, if cholinesterase inhibition is the cause of death, a local rather than a general inhibition is involved. The extent of inhibition after poisoning differed in strains differing in their resistance to diazinon poisoning.

9.16. Sawicki, R. M. (1961). The effect of "Safroxan" on the knock-down and the 24 hr. toxicity of commercial pyrethrum extract against house flies (*Musca domestica* L.). *Pyrethrum Post.* **6**, No. 2, 38–42.

The effectiveness of pyrethrum extract with "Safroxan" at 1:10 w/w against house flies during the first 15 minutes and 24 hours after treatment was compared with the effectiveness of a similar mixture of pyrethrum extract with piperonyl butoxide, and also with the extract alone. The flies, held during the treatment by suction, were treated topically with a measured drop of the substance tested.

Safroxan did not increase the effectiveness of pyrethrum during the first 15 minutes after treatment; it increased the toxicity of the extract 24 hours after treatment by about 3·5 times. Piperonyl butoxide, under similar conditions, slightly increased the knock-down activity of the extract (synergistic factor 1·9, 15 minutes after treatment); it increased the toxicity of the extract 24 hours after treatment very considerably (synergistic factor 9·6).

9.17. Sawicki, R. M. (1962). Insecticidal activity of pyrethrum extract and its four insecticidal constituents against house flies. II. Synergistic activity of piperonyl butoxide with the four constituents. *J. Sci. Fd Agric*, **13**, 260.

The toxicity to female house flies, 5–6 days old of the four insecticidal constituents of pyrethrum, combined at six ratios from 1:0·1 to 1:20 w/w) with piperonyl butoxide, was determined by a measured drop technique. The order and magnitude of the toxicities of the synergised constituents relative to synergised pyrethrum extract vary with the amount of synergist present. At 1:8 (pyrethroid piperonyl butoxide) the relative toxicities of the four constituents were: pyrethrum extract 1·0 (1·0), pyrethrin I 1·31 (0·85), cinerin I 1·28 (0·53), pyrethrin II 0·90 (1·37), cinerin II 0·58 (0·49). The relative toxicities of the constituents alone are given in brackets. At this ratio the synergistic factors of the four constituents were: pyrethrin I 18, cinerin I 27, pyrethrin II 6, cinerin II 14, pyrethrum extract 10. Possible explanations for differences of the extent to which the constituents are synergised are discussed.

9.18. Sawicki, R. M., Elliott, M., Gower, J. C., Snarey, M. & Thain, E. M. (1962). Insecticidal activity of pyrethrum extract and its four insecticidal constituents against house flies. I. Preparation and relative toxicity of the pure constituents; statistical analysis of the action of mixtures of these components. *J. Sci. Fd Agric.*, **13**, 172–185.

Pyrethrin I and II and cinerin I and II were isolated from commercial extract by displacement chromatography and also reconstituted from the naturally derived acids and alcohols. The four constituents from both sources had identical chemical, physical and insecticidal properties. The relative toxicities of the four constituents to female house flies (*Musca domestica* L.) determined by a measured-drop technique were: pyrethrum extract 1·0, pyrethrin I 1·3–1·5, pyrethrin II 0·9–1·0, cinerin I 0·5–0·6, cinerin II 0·4–0·5. The insecticidal activity of a mixture of the four constituents was tested statistically for simple similar joint action, when the probit lines are not parallel: the predicted results are in good agreement with the experimental data. The procedures for computing simple similar joint action are discussed and included in an appendix.

9.19. Sawicki, R. M. & Holbrook, Daphne V. (1961). The rearing, handling and biology of house flies (*Musca domestica* L.) for assay of insecticides by the application of measured drops. *Pyrethrum Post*, **6**, No. 2, 3–18.

The recent work on the biology and breeding techniques of house flies is reviewed.

Techniques are described for breeding house flies (*Musca domestica* L.) in pairs, small numbers (10–100) and on a large scale, as well as methods for handling, immobilising and treating the adult females with a measured-drop technique. The egg-laying medium consists of cotton-wool rolls soaked in a solution of milk and yeast. The eggs are separated in water from the egg-laying medium and are seeded on to the larval medium, which is made of 100 g. milk powder, 100 g. dried yeast, 20 g. agar, all made up in 1·0 l. of boiling water. The medium is then covered with saw-dust. The larvae which pupate in the saw-dust layer are separated from the medium by flotation in water. The adults are fed on dry milk powder and granulated sugar, liquid milk and a sugar solution. The full breeding cycle takes exactly a fortnight at 25·5°–26·5° C. For bio-assays the flies are cooled for 20 minutes at −20° C., then sexed in a cooling cabinet at 5°–10° C. The females are sorted into Petri dishes (15–20 flies per dish) and fed with a milk paste and sugar solution. They are left to recover at the required temperature. On the following day they are immobilised by chilling at −8° C. for a short time and are treated by topical application. They are replaced at the required temperature until death end-point is reached. Repeated experiments with this technique under identical conditions give reliable results.

9.20. Way, M. J. (1960). The effects of freezing temperatures on the developing egg of *Leptohylemyia coarctata* Fall. (Diptera, Muscidae) with special reference to diapause development. *J. Insect. Physiol.*, **4**, 92–101.

The later stages of diapause in the egg of *L. coarctata* are completed rapidly at −20° to −24° C. At −24° C. the rate of diapause completion is about 180 times faster than at −6° C. and about 80 times faster than at 3° C. These results suggest that there are at least two phases in diapause development—an initial synthesis, perhaps of neurohormone, which will not occur at −18° to −20° C. This is followed by a process ending in release of the synthesised material, which is greatly accelerated by relatively short exposures at −20° to −24° C.; longer exposures kill the eggs, probably because they freeze.

9.21. Way, M. J. (1961). Bean aphid control on field beans in relation to the flowering period and to honey bee poisoning. *Plant Path.*, **10**, No. 1, 14–20.

Insecticides applied at the best time for controlling bean aphid are especially dangerous to bees on February-sown crops, because these are likely to be in full bloom when they need spraying. Crops sown at other times will usually have flowered or not yet flowered, though some bees may be visiting them for extra-floral nectar.

Most spring bean crops are sown in March or April, and the main danger to bees seems to be from the unnecessarily late spraying of such crops.

Entomology Department

Doctoral Theses

10.1. Cockbain, A. J. (1961). Physiological studies on the flight of *Aphis fabae* Scop. Ph.D. Thesis, University of London.

10.2. Madge, D. S. (1961). Some aspects of the ecology and physiology of free-living mites. Ph.D. Thesis, University of London.

General Papers

10.3. Arnold, M. K. (1961). Bibliography of H. F. Barnes (1902–1960). *J. Soc. Bibl. nat. Hist.*, **4** (1), 35–43.

10.4. Banks, C. J. (1959). Effects of ants on the physiology and development of aphids. In *The Ontogeny of Insects. Acta Symposii de evolutione Insectorum.* Praha, 1959, pp. 329–332.

10.5. Banks, C. J. 1960. Some recent studies, involving the use of radioisotopes, of the feeding behaviour of two phytophagus insects. *Proc. of Int. Atomic Energy Agency.* Symposium on Radioisotopes and Radiation in Entomology, Bombay, 1960, pp. 175–180.

10.6. Edwards, C. A. 1961. Glasshouse Symphylids. Minist. Agric. advisory Leafl. **484**, 1–6.

10.7. Heath, G. W. 1961. Soil fauna investigations. *Rep. For. Res.* for 1960, 94–95.

10.8. Johnson, C. G. 1960. The present position in the study of insect dispersal and migration. *Rep. 9th Commonw. entom. Conf.* London 1960, pp. 140–145.

10.9. Johnson, C. G. 1961. Aphid dispersal and its bearing on the general character of insect migration by flight. *Anim. Behav.*, **9**, 3–4.

10.10. Johnson, C. G. 1961. Capsids: a review of current knowledge. In *Agriculture and Land Use in Ghana* (ed. J. B. Wills) London: Oxford University Press, pp. 316–331.

10.11. Johnson, C. G. 1961. The ecological approach to cocoa disease and health. In *Agriculture and Land Use in Ghana* (ed. J. B. Wills) London: Oxford University Press, pp. 348–352.

10.12. Raw, F. 1961. The agricultural importance of the soil mesofauna. *Soils and Fert.*, **24**, 1–2.

Research Papers

10.13. Banks, C. J., Brown, E. S. & Dezfulian, A.). (1961.) Field studies of the daily activity and feeding behaviour of Sunn Pest, *Eurygaster integriceps* Put., (Hemiptera, Scutelleridae) on wheat in North Iran. *Ent. exp. & appl.*, **4**, 289–300.

Individual Sunn Pests were tagged with Ta^{182} and their position recorded every ½ hour during daylight. At the beginning of the feeding period in early June they spent most of the time feeding on wheat ears, or in cracks in the soil when the air was hot and dry and the wheat dry and ripe. At the end of the feeding period in late June and just before migrating, long periods were spent in soil cracks, the insects moving actively but feeding infrequently.

Feeding began after sunrise, with two maxima, at 0800 hours and in the afternoon; it ceased at sunset, and there was little movement after dark. Feeding and air temperature were not simply correlated. Distribution of the pest in dry wheat near harvesting was associated with the distribution of two species of green weeds on which the insects fed.

10.14. Barnes, H. F., Arnold, M. K. & Heath, G. W. (1962). The gall midges of wild ox-eye daisy (*Chrysanthemum leucanthemum* L.) flowers, with the description of a new species. *Trans. Soc. Brit. Ent.*, **15** (1).

Four important gall midges, *Clinorhyncha leucanthemi* Kieffer, *Dasyneura chrysanthemi* sp. n., *Rhopalomyia hypogaea* F. Loew and *Contarinia chrysanthemi* Kieffer, and three species of *Cinodiplosis*, *Lestodiplosis* and *Phaenobremia*, have been recorded from wild ox-eye daisy flowers. Their taxonomy, distribution, biology and host-plant range are discussed, and a key is given for their separation.

The material in this paper was collected by Dr. H. F. Barnes in 1952–53 when searching for the source of a gall midge pest of cultivated Chrysanthemums: the paper was completed after Dr. Barnes' death.)

10.15. COCKBAIN, A. J. (1961). Low temperature thresholds for flight in *Aphis fabae*. *Ent. exp. & appl.*, **4**, 211–219.

The temperature thresholds for wing-beating and successful flight in alienicolae of *Aphis fabae* were found by flying tethered aphids in a falling temperature and by dropping free aphids in still air at different temperatures. The medium temperature thresholds for wing-beating, horizontal and upward flight were 6·5°, 13° and 15° respectively.

10.16. COCKBAIN, A. J. & HASTIE, A. C. (1961). Susceptibility of the bed bug, *Cimex lectularius* Linnaeus, to *Aspergillus flavus* Link. *J. Insect Path.*, **3**, 95–97.

Bed bugs kept at 30° and 90% relative humidity become naturally infected with *Aspergillus flavus* Link; this is apparently the first record of a fungus pathogenic to the bug. Infected second-instar and adult bugs lived for a significantly shorter time than non-infected controls.

10.17. EDWARDS, C. A. & (GUNN, E.). (1961.) Control of the Glasshouse Millipede. *Plant Path.*, **10**, 21–24 and Plate IV.

This millipede (*Oxidus gracilis* Koch) is essentially tropical and often attains excessively high numbers in glasshouses (500 millipedes sq. ft. of cucumber bed in one house). Observations on its biology and experiments on its control were made in glasshouses and laboratory. Materials tested were naphthalene, nicotine, parathion, lindane, dieldrin, diazinon, "Phosdrin" and aldrin. Naphthalene, nicotine, parathion and lindane gave quick initial kill, but their effects did not persist; lindane and dieldrin acted slower, but their effects persisted for months. The most effective was to drench soil, later covered with a polythene sheet, with a mixture of lindane and nicotine.

10.18. EDWARDS, C. A. & (DENNIS, E. B.) (1961). Phytotoxicity of insecticides and acaricides. I. Foliage sprays. *Plant Path.*, **10**, (2), 54–60.

Commonly used pesticides at once, twice and five times the normal dosage were sprayed on the foliage of some outdoor and indoor crops, for which they would normally be recommended, both with and without a wetter, and effects on the crops recorded. Of the more widely used commercial materials DDT, aldrin, dieldrin, "Roger," TEPP and parathion caused most damage, and phenkapton, fenson, chlorbenside, fluoracetamide, "Kelthane," "Phosdrin" and lindane caused some. The safest material tested was demeton methyl, which damaged no crop. Crops tested were peas, beans, lettuce, fodder beet, strawberries, cabbage, tomatoes, cucumbers. Cucumber was by far the most susceptible to damage, and cabbage and fodder beet were seldom harmed. Organophosphorus materials tended to produce edge chlorosis and scorch, which was also seen with malathion and diazinon. The chlorinated hydrocarbons usually caused distortion, leaf curl and leaf droop. At the highest dosages most materials severely affected growth and commonly caused necrosis.

10.19. EDWARDS, C. A. (1961). The ecology of Symphyla. Part III. Factors controlling soil distributions. *Ent. exp. & appl.*, **4** (4), 239–256.

Symphylids exhibit complex, seasonal, vertical migrations in soil. An attempt was made to assess the relative importance of different environmental and endogenous factors affecting these migrations; soil moisture content, soil temperature, the presence of plants at the soil surface, feeding cycles, moulting cycles, egg-laying and diurnal rhythms were studied in field and laboratory. Distributions of symphylids were correlated with soil moisture, and where this was equivalent to a relative humidity of less than 100% in the soil air, symphylids migrated to other soil layers. Symphylids survived long periods only in air of 100% relative humidity. The zone of optimum temperature for symphylids lies between 15° and 21°, and the survival zone is 2°–28°. *Scutigerella immaculata*, a phytophagous species, would enter a zone to feed where soil conditions were unfavourable. This species, which had feeding and non-feeding phases, migrated to deeper soil during non-feeding phases and for moulting.

Eggs were commonly laid at 5–15 cm. in the soil. No diurnal rhythm was found. Conditions favouring symphylids at the soil surface were the presence of plants there, much moisture and temperatures between 15° and 21°.

10.20. Heath, G. W. (1961). An investigation into leaf deformation in *Medicago sativa* caused by the gall midge *Jaapiella medicaginis* Rübsaamen (Cecidomyidae). *Marcellia.* **30**, Suppl., 185–221.

In simple leaf galls caused by the lucerne leaf midge *Jaapiella medicaginis* Rübs. the layer of cutin secreted by the epidermal cells within the larval chamber begins to disappear once the larva has hatched, and is soon lost from all the epidermal cells lining the larval chamber. The destruction of the cuticular layer presumably makes the epidermis permeable to the passage of solutes which stimulate gall formation.

10.21. Heath, G. W. (1962). The influence of ley management on earthworm populations. *J. Brit. Grassl. Soc.* (In the press.)

Results are given of 4 years' sampling for earthworms on a ley management experiment at Hurley, Berks. Both weight and numbers of earthworms increased in the ley, more so when grazed than when cut. The significance of this increase in terms of soil fertility and crop productivity is discussed.

10.22. Johnson, C. G. (1961). Syrphid (Dipt.) migration on the Norfolk Coast in August, 1960. *Ent. mon. Mag.*, **96** (1960), 196–7.

A low-level, orientated mass migration of sexually immature *Syrphus luniger* Mg. and *S. corollae* F. is described.

10.23. Johnson, C. G., Taylor, L. R. & Southwood, T. R. E. (1962). High altitude migration of *Oscinella frit* L. (Diptera, Chloropidae). *J. anim. Ecol.* (In the press.)

The vertical distribution in the atmosphere of panicle generation adults of *O. frit* was measured up to 1,000 feet for each hour during several days in August 1955. The relative density in the upper air in the early morning is low; it increases towards midday as turbulence and convection in the atmosphere increase and decreases again towards late afternoon. Maximum numbers in flight coincide with maximum upward transport, and the median height of flight (above which 50% of the airborne population fly) was about 1,300 feet at that time. Frit fly is thus adapted for high-altitude dispersal.

10.24. Madge, D. S. (1961). The control of relative humidity with aqueous solutions of sodium hydroxide. *Ent. exp. & appl.*, **4**, 143–147.

A gravimetric method is described for producing graded aqueous solutions of sodium hydroxide to give atmospheric relative humidities in steps of 10% between 0° and 40°.

10.25. Madge, D. S. (1961). "Preferred temperatures" of land arthropods. *Nature, Lond.*, **190**, 106–107.

10.26. Madge, D. S. (1961). The behaviour of free-living mites as affected by humidity. *Anim. Behav.*, **9**, 108.

Oribatid mites from various habitats behaved as "indicators" of the habitats. Thus a xerophyl species chose dry humidities initially and higher humidities after 4 days. A mesophyl species chose a high humidity initially, and a hygrophyl species did not react to linear or alternative humidity gradients. To a certain extent, starvation, desiccation and other internal and external factors changed responses to humidity. Individual mites differed from groups in their behaviour. The hygroreceptors are on the forelegs.

10.27. Taylor, L. R. & Carter, C. I. (1961). The analysis of numbers and distribution in an aerial population of Macrolepidoptera. *Trans. R. ent. Soc. Lond.*, **113**, 369–386.

In three seasons' suction trapping at five heights population structure was very consistent. Moths occasionally reached very high densities, comparable in biomass with aphid migrations. Diurnal flight periodicity and height of flight were highly specific. Light traps selected some species 5,000 times as strongly as others, but their efficiency varies so much during the night that they are useless for measuring flight periodicity. With a suction-trap catch of only 169 specimens in 3 years, the flight temperature threshold, height of flight, diurnal periodicity and phenology of *Agrochola lychnidis* were accurately defined.

Bee Department

General Papers

11.1. Bailey, L. (1961). European foulbrood. *Amer. Bee J.*, **101**, 89–92.

11.2. Free, J. B. (1961). The orientation of honeybees to their hives. *Anim. Behav.*, **9**, 231 only.

11.3. Free, J. B. (1961). The social organisation of the bumblebee colony. *Rep. cent. Ass. Brit. Beekeep. Ass.*, 1–11.

11.4. Simpson, J. (1961). Nest climate regulation in honey bee colonies. *Science*, **133**, 1327–1333.

Research Papers

11.5. Bailey, L. (1961). An improved medium for the isolation of *Streptococcus pluton* (White). *J. Insect Path.*, **3**, 100 only.

Including soluble starch in the special medium necessary to cultivate *S. pluton* greatly facilitates its isolation, but is usually unnecessary for its subsequent propagation.

11.6. Bailey, L. (1961). The natural incidence of *Acarapis woodi* (Rennie) and the winter mortality of honey bee colonies. *Bee World*, **42**, 96–100.

The incidence of *Acarapis woodi* at Rothamsted decreased strikingly after seasons of good nectar-flow. The mortality of colonies in winter was not obviously correlated with infestation except in the few colonies with more than 50% of bees infested. There was no obvious difference between the susceptibility of bees of three different origins to infestation. Less that 2% of colonies in England and Wales are estimated to suffer measurably from *A. woodi*.

11.7. Butler, C. G. (1961). The scent of queen honeybees (*A. mellifera* L.) that causes partial inhibition of queen rearing. *J. Insect Physiol.*, **7**, 258–264.

Virgin queens, like mated, laying ones, produce a scent that partially inhibits worker bees from rearing queens. When this scent and enough of the queen's other inhibitory factor, 9-oxodecenoic acid, are present together inhibition is complete. Old, mated, laying queens produce more inhibitory scent than virgins, which produce similar amounts irrespective of their age. Like 9-oxodecenoic acid, the inhibitory scent occurs all over a queen's body. Unlike this acid, which is produced mainly in a queen's mandibular glands, the inhibitory scent probably comes from glands in many parts of her body. The inhibitory scent is probably distinct from the attractive scent.

11.8. Butler, C. G. (Callow, R. K. & Johnston, N. C.). (1961.) The isolation and synthesis of queen substance, 9-oxodec-*trans*-2-enoic acid, a honeybee pheromone. *Proc. Roy. Soc.* B., **155**, 417–432.

A method is described for isolating " queen substance ", which is produced in the mandibular glands of queen honeybees and inhibits both queen rearing by worker honeybees and the development of their ovaries. Queen substance was identified as 9-oxodec-*trans*-2-enoic acid and its identity confirmed by synthesis. The synthetic and natural materials have the same biological activity. The methyl ester of 9-oxodecenoic acid is also active.

Neither the natural nor the synthetic material completely inhibits queen rearing, whereas the presence of a live queen does. The other inhibitory factor is " queen scent ", which also on its own does not completely inhibit queen rearing. Queen scent plus 9-oxodecenoic acid cause complete inhibition.

9-oxodecenoic acid did not affect the reproduction of any of the small mammals on which it was tested; nor did it have any pharmacological activity in a wide range of tests.

11.9. Free, J. B. (1960). The behaviour of honeybees visiting flowers of fruit trees. *J. Anim. Ecol.*, **29**, 385–395.

Foraging bees were watched on apple, apricot, peach, pear, plum and sweet cherry flowers. During a single flower visit a bee either approached the nectary from the top of the stamens, sometimes collecting pollen in the process, or scrabbled over the anthers and gathered pollen only, or, far less often, did both. Bees also obtained nectar from apple flowers by inserting their tongues between the filaments of the stamens from the side, often without touching the anthers; the proportion of nectar-gatherers that visited apple flowers in this way varied with the flexibility, height and thickness of the filaments of the variety concerned.

During a single trip, or part of a trip, most bees kept to one type of behaviour, but some collected pollen only on some flower visits and nectar, with or without pollen, on others. The proportions of the different types of flower visits varied from day to day and at different times on the same day.

Bees visited an average of about two trees per trip and tended to change to trees nearest to those on which they started working. Except on pears, pollen-gatherers spent less time per flower and visited more flowers per tree than nectar-gatherers. On unfavourable days bees spent longer per flower and visited fewer flowers per tree.

11.10. Free, J. B. (1960). The distribution of bees in a honey-bee (*Apis mellifera* L.) colony. *Proc. R. ent. Soc. Lond.* A, **35**, 141–144.

Bees of all age groups were almost equally distributed on combs of young larvae, old larvae and eggs. The lowest percentages of bees with undeveloped hypopharyngeal glands were on the combs of larvae, and the highest percentages with developed glands on the food stores, combs of sealed and emerging brood and on combs of larvae. It is, therefore, improbable that nurse bees of different ages feed larvae of different ages. An individual worker may vary the composition of its glandular secretion to suit the age of the larva concerned, or, less probably, the glandular secretion differs in individual bees irrespective of their ages.

11.11. Free, J. B. (1961). Hypopharyngeal gland development and division of labour in honey-bee (*Apis mellifera* L.) colonies. *Proc. R. ent. Soc. Lond.* A, **36**, 5–8.

Confining newly emerged workers for different lengths of time, and on different diets, changed the development of their hypopharyngeal glands and the ages at which they began foraging.

11.12. Free, J. B. (1961). The stimuli releasing the stinging response of honeybees. *Anim. Behav.*, **9**, 193–196.

The factors inducing honeybees to sting were investigated by comparing the number of times cotton-wool balls treated in different ways were stung.

Dark-coloured balls were stung more than light-coloured, particularly against dark backgrounds, and materials of rough texture were stung more readily than smooth. Increasing rate of movement increased stinging.

The odour associated with sting venom encouraged further stinging. This odour could be masked by smoke. General bee odour encouraged stinging little, if at all, and bees were more inclined to sting balls with the odour of their own than of another colony. Animal scent and the smell of human perspiration encouraged stinging and various insect repellents discouraged it.

11.13. FREE, J. B. & SPENCER-BOOTH, YVETTE. (1960.) Chill-coma and cold death temperatures of *Apis mellifera*. *Ent. exp. & appl.*, **3**, 222–230.

Worker bees have a lower chill-coma temperature than drones or queens; it is influenced by their acclimatisation temperature, as is their food consumption at a given temperature. Most bees die after fifty hours in chill-coma and survive longer at 5° than at 0° or 10°. Cold death occurs between −2° and −6° and is unaffected by acclimatisation. "Winter" bees have lower chill-coma temperatures than "summer" bees, but after acclimatisation to 35° there is no difference. The chill-coma temperature of "summer" bees decreases with age, irrespective of acclimatisation.

11.14. FREE, J. B. & SPENCER-BOOTH, YVETTE. (1961.) Further experiments on the drifting of honey-bees. *J. agric. Sci.*, **57**, 153–158.

Worker bees learned the colour of their hive close to the hive entrance and took little or no notice of colours above the lower brood-chamber. They orientated to a colour below the entrance more than to one above. They did not learn combinations of colours. They distinguished between certain symbols placed immediately above the hive entrance and learned the height of their hive and the height of its entrance above ground.

More worker bees and drones from queenright colonies drifted to queenless than to queenright colonies. Drones expelled from queenright colonies did not drift to queenless ones.

11.15. FREE, J. B. & SPENCER-BOOTH, YVETTE. (1961.) The effect of feeding sugar syrup to honey-bee colonies. *J. agric. Sci.*, **57**, 147–151.

In the spring, summer and autumn of 1958 and 1959, colonies were fed concentrated (62%) or dilute (40%) sugar syrup, or remained unfed. They were observed for the week before, during and after feeding. The amount of syrup taken increased during the year, more of the concentrated than of the dilute being taken, but this ratio decreased during the year. The concentration fed made no apparent difference to colony gain in weight relative to the sugar taken. Feeding increased brood rearing in 1958 (bad weather), but not in 1959 (good weather). It usually increased pollen-collection but feeding concentrated syrup probably decreased nectar-gathering.

11.16. FREE, J. B. & SPENCER-BOOTH, YVETTE. (1961.) Analysis of honey farmers' records on queen rearing and queen introduction. *J. agric. Sci.*, **56**, 325–331.

Sealed queen cells and virgin queens were accepted better by colonies which had queen cells, or had been queenless more than two days, than by colonies without sealed queen cells. Younger queen cells were better accepted than older ones in recently dequeened colonies. Mated, laying queens were less successfully introduced to colonies which previously had virgin queens, queen cells, or laying queens and queen cells, than to colonies that previously had laying queens only. Thus, success was greatest when the queen removed from the recipient colony was at the same, or immediately previous, stage of development as the queen being introduced. In June and July introduction of queen cells and virgin queens was more successful, and that of mated, laying queens less successful, than in May and August, suggesting the importance also of the physiological state of the colony.

11.17. Free, J. B. & Spencer-Booth, Yvette. (1961.) Effect of temperature on *Apis indica* workers. *Nature, Lond.*, **190**, 933.

Small groups of *A. indica* workers, like those of *A. mellifera*, respond to low temperature by taking more food, indicating increased metabolism and heat production. The mortality of both species was similar at high temperatures, but was greater for *A. indica* at low temperatures. *A. indica* workers have a higher chill-coma temperature than *A. mellifera*. These results indicate that *A. mellifera* is better adapted to temperate climates than *A. indica* but fail to show that *A. indica* has any corresponding adaptation to the tropics.

11.18. Riedel, I. B. M. & Simpson, J. (1961). Absence of salivary invertase in queen and drone honey bees. *Experientia*, **17**, 365.

Queens and drones have little, if any, invertase in their salivary glands. They take no part in honey storage, so probably do not need the enzyme in their saliva.

Statistics Department

General Papers

12.1. Healy, M. J. R. (1962). The place of mathematics in biology. *Biology*. (In the press.)

12.2. Vernon, A. J. (1961). Control of cocoa capsids in West Africa. *Chem. & Ind.*, 1219–1220.

Research Papers

12.3. Buck, S. (1961). The use of rainfall, temperature, and actual transpiration in some crop-weather investigations. *J. agric. Sci.*, **57**, 355–365.

This paper reports various investigations of the effects of meteorological factors on the yields of crops in England and Wales. The investigations were undertaken primarily with the objects of seeing: (*a*) whether variations in temperature had any direct effect on yields, and (*b*) whether Penman's concept of actual transpiration gave a better measure of the total effect of rainfall than the use of a multiple regression on variates representing total rainfall and its distribution.

The effect of temperature and its seasonal distribution on the yields of wheat on various plots of the classical wheat experiment on Broadbalk field at Rothamsted was studied in conjunction with rainfall and its seasonal distribution, using the regression method devised by Fisher. Variations in temperature were found to show no effects on the final yields.

The relationship between actual transpiration and yield was investigated for the Broadbalk field and for sugar beet and potatoes, using average yields determined by sampling methods, for various districts in England and Wales. For sugar-beet virus yellows infection, and for potatoes blight attack, were also taken into account.

No relationship between actual transpiration and wheat yields on Broadbalk field was found, but sugar beet and potatoes both showed a positive association between actual transpiration and yield except for sugar beet in the Spalding area, where there is a high water table. Actual transpiration was in general more effective than a regression on total rainfall and its distribution accounting for variations in yield. As might be expected, virus yellows and blight also account for a good deal of the variation in yield.

12.4. (Burrell, R. J. W.), Healy, M. J. R. & (Tanner, J. M.) (1961). Age at menarche in South African reserve-domiciled Bantu schoolgirls. *Hum. Biol.*, **33**, 250–261.

The distribution of age at menarche has been studied in 47,420 Bantu schoolgirls living in the Transkei Reserve, South Africa. The girls were interviewed by women Bantu teachers and asked whether or not menstruation had occurred. Dates of birth were taken from the school admission registers and

are believed to be nearly all correct to the nearest month. The girls were divided into those coming from " poor " and those from " not-poor " homes, as judged by the school principals.

The proportions menstruating plotted against age were fitted by two alternative sigmoid curves, the cumulative Normal and the logistic. The latter gave a slightly better fit for the not-poor group and was superior for the poor group. There was an effect of month of birth, girls born early in the calendar year tending to menstruate some four months later than those born towards the end of the year. The mean age at menarche was $15{\cdot}42 \pm 0{\cdot}04$ years for the poor group and $15{\cdot}02 \pm 0{\cdot}03$ years for the not-poor group. In addition to the later mean, the poor group were more variable in age at menarche than the not-poor group.

12.5. (Cooke, Patricia, Jones, Morley R., Mather, K.), Bonsall, G. W. & (Nelder, J. A.). (1962.) Estimating the components of continuous variation. *Heredity*. (In the press.)

Two inbred lines of *Drosophila melanogaster* were crossed reciprocally. In addition to the F_1's, and F_2's biparental progenies of the third generation were raised from both crosses. The number of sternopleural chaetae were counted in all these generations and components of variation (D, H, E_1 and E_2) for this character were estimated using the method devised by Mather (1949). Replicate estimates were obtained by using data from males and females separately in the two halves of the experiment stemming from the reciprocal crosses. The results from one sib of females proved to be aberrant for reasons which are not known. The analyses yielded no clear indication of any effect of linkage.

A weighted method which allows for differences in precision and correlation among the basic statistics has been described by Nelder (1960), and this was applied to the results. The weighted analysis provides clear evidence of the effects of linkage and also brings out more forcibly the abnormality of the results for the aberrant females.

The simple unweighted analysis yields estimates of the components of variation which do not differ significantly from those resulting from the weighted analysis. The relative efficiency of the unweighted analysis varies from 60% to over 90% for the various components of variation over the four parts of the experiment.

A further set of data for flowering time and plant height in *Nicotiana rustica* were similarly analysed by both methods. Though the broad structure of the experiment was similar to that of the one with *Drosophila*, the relative precisions of the statistics it yielded were somewhat different. The unweighted estimates of the components stood in very much the same relation to the weighted estimates as in the *Drosophila* experiment, and the efficiency of the weighted method was also much the same.

12.6. (Dermott, W.) & Lessells, W. J. (1962). The use of gypsum on soils which have not been flooded by seawater. *Crop Husbandry*. (In the press.)

The effects of gypsum and lime on soil structure and crop yield were measured in fourteen experiments, on soils not flooded by sea-water but heavy in texture and on which it was difficult to obtain satisfactory tilths. Four of the experiments were on restored opencast coal sites.

Some improvement in soil structure was noted in seven out of the fourteen experiments, but it was slight and temporary. No improvement was noted following the use of ground limestone, chalk or (one experiment only) burnt lime.

In none of the experiments was there a significant yield response to gypsum or to lime, and the results as a whole are consistent with the idea that gypsum did not affect responses at any site.

12.7. Gower, J. C. (1962). The handling of multiway tables on computers. *Comput. J.*, **4**, 280–286.

A notation is proposed which concisely describes many forms of table manipulation in terms of a concept called *scanning*. Methods of programming a scanning sub-routine are discussed, and examples are given of the use of the scanning notation to formulate typical table operations in symbolic form. It is often convenient to store marginal values (usually totals or means) with the

main table, and this requires some modification of the notation and the subroutine. Proposals are outlined for including scanning facilities in automatic programming languages, and examples are given of the form this could take in a language related to the Mercury Autocode compiler.

12.8. Healy, M. J. R. & Gower, J. C. (1961). Aliasing in partially confounded experiments. *Biometrika*, **48**, 218–220.

In factorial experiments with factors at more than two levels it is common practice to employ in the scheme of confounding a set of contrasts different from those used in the analysis of the experiment. Unless the confounding is balanced, this can lead to estimates of these latter contrasts being wholly or partly correlated. Details are worked out for experiments of the type 3^n and $2^m \times 3^n$.

12.9. Leech, F. B. (1962). A statistical technique suitable for the analysis of farm surveys of fertility. *Proc. Fourth Int. Congr. Animal Reproduction.* (In the press.)

After showing how to obtain an index of herd fertility adjusted for factors known to influence individual matings, the index is used (giving unit weight to each farm) to examine the effects of environment or management factors on herd fertility.

12.10. Patterson, H. D. & (Williams, R.). (1962.) The residual effects of phosphorus fertilisers on yields of arable crops: preliminary results of six rotation experiments. *Exp. Husbandry.* (In the press.)

Six long-term experiments on the direct and residual effects of four phosphorus fertilisers, superphosphate, rock phosphate, basic slag and dicalcium phosphate, on yields of arable crops are in progress at N.A.A.S. Experimental Husbandry Farms. The results of up to 7 years are summarised and discussed.

Responses to direct applications agree fairly closely with the conclusions drawn by Cooke (1956) and Cooke and Widdowson (1959) from many 1-year experiments. Superphosphate gave consistently good responses, but the more insoluble fertilisers can give poor results. Thus, rock phosphate was of little or no value for any of the crops tested on neutral soils and gave relatively small increases in yields of potatoes on acid soils. With such soils the efficiency of rock phosphate decreased as the rate of application increased. Basic slag also gave poor yields of potatoes except on one acid soil. Dicalcium phosphate gave the best yields of potatoes, the only example of the less-soluble fertilisers being better than superphosphate in the year of application, but there is evidence that even this advantage may be lost as residues accumulate.

The experiments provide information on the residual effects of the fertilisers: (*a*) in the absence of fresh fertiliser; and (*b*) in the presence of a further application of fertiliser. Fertilisers giving the largest responses in the year of application also tended to produce the largest residual effects of type (*a*). In one exception, swedes at Trawscoed, rock phosphate residues were more effective than superphosphate residues even though direct application of the mineral form gave smaller responses. Residual effects of type (*b*) are more important, however, as the residues did not give full yields on their own. At present the experiments provide information only on the residual effects obtained in the presence of small amounts of fertiliser, but it is clear that residual effects of type (*b*) depend on the type of fertiliser used and can be very much smaller than residual effects of type (*a*). Indications are that superphosphate gives the largest effects of type (*b*), but the experiments will have to continue for several more years before the full practical value of these effects can be assessed.

12.11. Sawicki, R. M., Elliott, M., Gower, J. C. (Snarey, M. & Thain, E. M.). (1962.) Insecticidal activity of pyrethrum extract and its four insecticidal constituents against house flies. I. Preparation and relative toxicity of the pure constituents; statistical analysis of the action of mixtures of these components. *J. Sci. Fd Agric.*, **13**, 172–185.

(For summary see above no. 9.18.)

12.12. (Wilson, A. R., Twiss, P. T. G.) & Lessells, W. J. (1962). Weight-loss and sprouting of bulk-stored maincrop potatoes. *Eur. Potato J.* (In the press.)

Maincrop potatoes stored in bulk under normal commercial conditions in England may be expected to lose by shrinkage on average from 2·5% by the end of January to almost 7% by the end of May in indoor stores, and from 2·5% by the end of February up to 5% by the end of May in clamps. These figures refer only to potatoes remaining sound throughout storage, and do not include any losses from rotting.

Figures from indoor stores suggest that use of forced-draught ventilation in the early winter may decrease losses by shortening the time necessary to achieve the " holding " temperature. Figures are included illustrating the effect of position in clamp or store on weight loss.

12.13. Yates, F. (1962). Computers in research—promise and performance. *Comput. J.* (In the press.)

Computers have been extensively used to solve problems involving really heavy computation, such as occur in crystallography, molecular physics and aircraft design, but their use for research statistical calculations has developed relatively slowly. In large part this comes from failure to develop adequate programmes: the solution appears to lie in the construction of specialised autocodes for different classes of statistical problem. Such programmes can be developed only by groups of statistical experts, who can appreciate what is really required, and can advise on their use when written. Specialist computer installations, devoted to some particular subject, have the great advantage that they can carry an adequate team of experts on their own staff. (Presidential Address to the British Computer Society.)

12.14. Yates, F. & Healy, M. J. R. (1962). Electronic computation and data processing for research statistics. *Bull. Inst. int. Statist.*, **4**, 273–279.

This paper discusses the problems of using an electronic computer in a research statistics department. The requirements of such a department differ greatly from those of large-scale data processing; jobs tend to be smaller, a wide variety of different problems arise in an unpredictable manner; and the type of analysis to be applied to a problem can often be decided only when the results of a previous analysis have been inspected. The method being developed at Rothamsted involves the provision of several standard general programmes, each able to handle a whole class of problems. The specification of the requirements of a particular problem can then be greatly simplified. Such programmes must include facilities for extracting relevant data from a large bulk stored on magnetic tape, and should also have editing facilities.

A general programme for survey analysis has been written and used; this is described in detail. Other general programmes for the analysis of experimental designs, time series and other types of data are being considered.

We consider that computing facilities can be most effectively used when different centres specialise to some extent. This thesis raises problems of its own, particularly when a large computer is installed, and we discuss some of these problems in connection with the new computer we hope to install shortly.

Woburn Experimental Station

15.1. Mann, H. H. (1961). Classification of the tea plant. *Nature, Lond.*, **191**, 409.

The number of leaf veins has not been a satisfactory criterion for separating varieties of tea.

Dunholme Field Station

General Papers

16.1. Adams, S. N. (1961). Sugar-beet fertiliser experiments in 1960. *Min. Agric. Sugar Beet Res. & Educ. Comm. Pap. 626.*

16.2. Adams, S. N. (1961). The manuring of sugar beet. *Chem. & Ind.*, 564–566.

16.3. Adams, S. N. (1961). The role of sodium in manuring sugar beet in Great Britain. *Rep. 24th Winter Cong. int. Inst. Sugar Beet Res.*, Brussels 1961, 311–316.

16.4. Adams, S. N. (1961). Fertilisers for beet. Can they be applied before ploughing in the autumn? *Brit. Sug. Beet Rev.*, **29**, 153.

16.5. Byford, W. J. (1961). Seed dressings: an important development. *Brit. Sug. Beet Rev.*, **29**, 119.

16.6. Dunning, R. A. (1961). Aphids and yellows in 1960 and prospects for 1961. *Brit. Sug. Beet Rev.*, **29**, 117–118.

16.7. Dunning, R. A. (1962). Insecticides and fungicides used to control sugar beet pests and diseases. *Chem. & Ind.*, 155–158.

16.8. Hull, R. (1961). A practical man's guide to sugar beet seed. *Fmr & Stk-Breed.*, 31 January, 1961.

16.9. Hull, R. (1961). Sugar-beet seed—a product of research developed to suit modern needs. *Centr. Office of Information. In series issued for International Seed Year.*

16.10. Hull, R. (1961). The health of the sugar-beet crop in Great Britain. *J. R. agric. Soc.*, **122**, 101–112.

16.11. Hull, R. (1961). Yellows in 1961. *Brit. Sug. Beet Rev.*, **30**, 83–84.

16.12. Hull, R. (1961). Sugar-beet yellows in Great Britain, 1960. *Plant Path.*, **10**, 149–50.

16.13. Hull, R. (1961). Sugar-beet yellows in Europe. *Rep. 1st Joint Mtg int. Inst. Sug. Beet Res. and Amer. Soc. Sug. Beet Tech.*, 1961.

Research Papers

16.14. Adams, S. N. (1962). The response of sugar beet to fertiliser and the effect of farmyard manure. *J. agric. Sci.*, **58**, 219–226.

Forty-nine 3^3 factorial experiments in 1957–60 tested the response of sugar beet to 0·6, 1·2, 1·8 cwt. N, 0·0, 0·5, 1·0 cwt. P_2O_5 and 0·8, 1·6, 2·4 cwt. K_2O/acre. On forty-one of the sites the experiment was repeated in the presence of 12 tons FYM/acre.

Optimum dressings for sugar beet without FYM were 1·0 cwt. N, 0·5 cwt. P_2O_5 and 1·6 cwt. K_2O/acre. Exceeding the optimum nitrogen dressing decreased sugar yield, although the yield of tops was increased. Many fields required only 0·6 cwt. N/acre, especially those in which the beet followed less than two cereal crops. Response to phosphate and potash did not differ much in different experiments, and the national optimum would have been satisfactory for nearly all fields.

The main value of dung for beet was in the N, P and K it provided. With FYM, optimum dressings for sugar yield were only 0·6 cwt. N, 0·0 cwt. P_2O_5 and 0·8 cwt. K_2O/acre.

The responses on different soil types are discussed.

Soil Survey of England and Wales

17.1. *Soil Map of Bangor*, Sheet 106 (3rd Edn.). Southampton: Ordnance Survey, 1961.

17.2. *Soil Map of Aylesbury*, Sheet 238 (3rd Edn.). Southampton: Ordnance Survey, 1961.

17.3. Ashley, G. D. (1961). Grassland and soil structure. *J. Brit. Grassl. Soc.*, **16**, 156–159.

Discussion of some factors and problems in producing a stable crumb structure under British conditions with suggestions for techniques to form a more suitably structured profile.

17.4. Bascomb, C. L. (1961). A calcimeter for routine use on soil samples. *Chem. & Ind.*, 1826–7.

A simple volumetric apparatus is described that accommodates a larger sample ($\lessgtr 1$ gm. $CaCO_3$) than the generally used Collin's calcimeter without loss of accuracy, thus making subsampling less difficult.

17.5. Bridges, E. M. (1961). Aspect and time in soil formation. *Agriculture, Lond.*, **68**, 258–263.

For soils developing on reclaimed overburden left in "hill and dale" relief, aspect is at least as important as time, and soil forms very slowly on north-facing slopes. Complete larch canopy gives moist soil conditions and lowers pH values; with less canopy the values are higher on this very mixed parent material.

17.6. Crampton, C. B. (1961). An interpretation of the micromineralogy of certain Glamorgan soils: the influence of ice and wind. *J. Soil Sci.*, **12**, 158–171.

Criteria for recognising the presence of wind-blown materials are discussed. Some soil series are shown to be formed essentially on local ice-produced drift, others to be derived mainly from the underlying rock with additional ice- and wind-borne material; yet others are influenced by the underlying rock and wind-blown material only.

17.7. Crompton, A. (1961). A brief account of the soils of Yorkshire (with map). *J. Yorks. Grassl. Soc.* No. **3**, 27–35.

17.8. Hirst, J. M., Le Riche, H. H. & Bascomb, C. L. (1961). Copper accumulation in the soils of apple orchards near Wisbech. *Plant Path.*, **10**, 105–108.

(For summary see above no. 7.20.)

17.9. Mackney, D. (1961). A study of podzolisation under oakwood and heath in Central England. *J. Soil Sci.*, **12**, 23–40.

The following sequence of processes probably occurs while a slightly podzolised sandy brown earth develops into a humus–iron podzol: translocation of clay, association of iron with organic matter and slight eluviation of iron, strong iron eluviation, eluviation of organic matter. Pollen analysis helps to establish that podzolisation occurs under oakwood where edaphic environments are favourable.

17.10. Thomasson, A. J. (1961). Some aspects of the drift deposits and geomorphology of south-east Hertfordshire. *Proc. geol. Ass., Lond.*, **72**, 287–302.

Further data on the lithology and mineralogical composition of the deposits are presented and their chronology and derivation are discussed. The asymmetric valleys in this and neighbouring areas are discussed.

Publications of the Rothamsted Experimental Station

(*obtainable from the Librarian*)

REPORT, ROTHAMSTED EXPERIMENTAL STATION

1908–1914 (annual; 1908 out of print)	1/- each
1915–17, 1918–20 (triennial; 1915–17 out of print)	
1921–22, 1923–24, 1925–26, 1927–28 (biennial) ...	2/6 each
1929–1937 (annual; 1933 out of print)	
1938	Out of print
1939–45 (one issue covering the war years) ...	5/- each
1946, 1947	3/- each
1948, 1949	5/- each
1950–1954 (annual)	7/6 each
1955	8/6
1956–1960 (1957 out of print)	10/- each
1961	15/-

THE NUMERICAL RESULTS OF THE FIELD EXPERIMENTS

1961	10/-

ROTHAMSTED MEMOIRS ON AGRICULTURAL SCIENCE

1 (1847–63)—**8** (1896–1912), 1863–1913 ...	Out of print
9 (1909–16)—**11** (1920–22), 1919–24	32/6 each
12 (1922–25), 1926	33/6
13 (1925–27), 1928	Out of print
14 (1928–30), 1930	35/-
15 (1922–31)—**23** (1939–40), 1932–40	36/- each
24 (1940–41)—**31** (1952–53), 1947–56	60/- each
32 (1953–55)—**37** (1958–59)	80/- each

(**1–7** are in demy octavo, **8–35** in royal octavo.)

ROTHAMSTED MEMOIRS, FROM THE " PHILOSOPHICAL TRANSACTIONS "

1 (1861–89), 1893	
2 (1880–1900), 1893	Out of print
3 (1859–83), 1893	
4 (1914–34), 1934	20/-

(These are published in quarto.)

ROTHAMSTED CONFERENCE REPORTS: being papers by practical farmers and scientific experts.

† *The manuring of potatoes.* (1925; 1/6.)
* (1) *The growing of lucerne.* (1926.)
(2) *The culture and manuring of fodder crops.* (1926.)
(3) *Green manuring.* (1927.)

† Unnumbered. * Out of Print.

(4) *The culture and manuring of sugar beet.* (1927; 2/6.)
(5) *The art and science of cultivation.* (1927; 2/-.)
(6) *Power for cultivation and haulage on the farm.* (1928; 2/6.)
(7) *Malting barley.* (1928; 2/6.)
(8) *Recent changes in systems of husbandry in England.* (1929.)
(9) *The Hertfordshire agricultural situation: Can it be improved?* (1929; 2/-.)
(10) *The growth of cheaper winter food for live stock.* (1930; 2/6.)
(11) *The making of new grassland: experiences of practical farmers.* (1931; 2/6.)
(12) *The place and management of sheep in modern farming.* (1931; 1/6.)
*(13) *The technique of field experiments.* (1931; 1/6.)
(14) *Mechanization and British agriculture.* (1932; 2/6.)
(15) *Recent developments in market gardening.* (1932; 2/-.)
(16) *Problems of potato growing.* (1934; 2/-.)
(17) *Modern changes in the treatment of light soil.* (1934; 2/-.)
*(18) *Brood diseases of bees.* (1934.)
(19) *The production of pigs for bacon.* (1935; 1/6.)
*(20) *The cause and control of swarming bees.* (1935.)
(21) *The use of electricity in agriculture.* (1936; 2/-.)
(22) *Diseases of bees.* (1936; 1/6.)

Numbers 1–20 were also published in four bound volumes:

Volume 1 (*Conferences* 1–5)	Out of print.
Volume 2 (*Conferences* 6–10)	10/-.
Volume 3 (*Conferences* 11–15)	10/-.
Volume 4 (*Conferences* 16–20)	Out of print.

GUIDE TO THE EXPERIMENTAL FARMS. (1962; 1/-.)
INVESTIGATIONS IN THE LABORATORIES. (1957; 6*d*.)
ROTHAMSTED, 1843–1943: the work and history of the departments. (1943.)

ROTHAMSTED EXPERIMENTAL STATION LIBRARY

Catalogue of the printed books on agriculture published between 1471 and 1840, by Mary S. Aslin. (Rothamsted, 1926.)*
—*Second Edition.* (Rothamsted, 1940. Cloth, 15/-; paper, 12/-.)
—*Supplement . . .* List of additions since 1940. (Rothamsted, 1949; paper, 2/6.)
Catalogue of serial publications in the Library, 1953. Edited by D. H. Boalch. (Rothamsted, 1954; 17/6.)
Catalogue of serial publications in the West Building Library at Rothamsted (Entomology, Insecticides, Mycology), March, 1956. Edited by D. H. Boalch. (Rothamsted, 1956; mimeographed; 2/-.)
The Manor of Rothamsted: [a history and guide], by D. H. Boalch. (Rothamsted, 1953; 7/6.)
Prints and paintings of British farm livestock 1780–1910: a record of the Rothamsted Collection, by D. H. Boalch. (Rothamsted, 1958; one guinea.)

*Out of Print.

Books by Present and Past Members of the Rothamsted Staff

*1911 HALL, Sir A. D. & RUSSELL, Sir E. J. A report on the agriculture and soils of Kent, Surrey and Sussex. London: H.M.S.O.

*1913 RUSSELL, Sir E. J. *The fertility of the soil.* Cambridge University Press.

*1917 HALL, Sir A. D. *The book of the Rothamsted experiments.* 2nd edition. London: John Murray.

*1917 RUSSELL, Sir E. J. *Manuring for higher crop production.* Cambridge University Press.

*1920 BRENCHLEY, Winifred E. *Weeds of farmland.* London: Longmans, Green & Co.

*1922 GREY, Edwin. *Reminiscences, tales and anecdotes of the laboratories, staff and experimental fields, 1872–1922.* Rothamsted Experimental Station.

*1923 RUSSELL, Sir E. J. *et al. The micro-organisms of soil,* by E. J. Russell and the staff of the Rothamsted Experimental Station. London: Longmans, Green & Co.

*1924 RUSSELL, Sir E. J. *Plant nutrition and crop production,* being the Hitchcock Lectures, 1924. University of California Press and Cambridge University Press.

*1925 DAVIDSON, J. *A list of British aphides. . . .* London: Longmans, Green & Co.

*1927 BRENCHLEY, Winifred E. *Inorganic plant poisons and stimulants.* 2nd edition, revised and enlarged. Cambridge University Press.

*1929 HALL, Sir A. D. *The book of the tulip.* London: Martin Hopkinson.

*1931 KEEN, Sir B. A. *The physical properties of the soil.* London: Longmans, Green & Co.

*1932 CUTLER, D. Ward. *Evolution, heredity and variation.* London: Christophers.

*1933 GOODEY, T. *Plant parasitic nematodes.* London: Methuen.

*1933 HALL, Sir A. D. & CRANE, M. B. *The apple.* London: Martin Hopkinson.

*1933 RUSSELL, Sir E. J. *The farm and the nation.* London: George Allen and Unwin Ltd.

*1935 CUTLER, D. Ward & CRUMP, Lettice M. *Problems in soil microbiology.* London: Longmans, Green & Co.

*1935 GREY, Edwin. *Cottage life in a Hertfordshire village.* St. Albans: Fisher Knight & Co.

*1936 RUSSELL, Sir E. J. & VOELCKER, J. A. *Fifty years of field experiments at the Woburn Experimental Station.* With a statistical report by W. G. Cochran. London: Longmans, Green & Co.

* Out of Print.

*1939 NICOL, Hugh. *Microbes by the million.* Harmondsworth: Penguin Books Ltd.

*1939 RUSSELL, Sir E. J. *Artificial fertilizers in modern agriculture.* Ministry of Agriculture and Fisheries Bulletin no. 28, [3rd edition]. London: H.M. Stationery Office.

*1939 RUSSELL, Sir E. J. *Report on the work of the Imperial Council of Agricultural Research in applying science to crop production in India.* Reprinted. Simla: Government of India Press.

1940 NICOL, Hugh. *Plant growth substances.* 2nd edition. London: Leonard Hill, 3/6.

1941 RUSSELL, Sir E. J. *English farming.* London: William Collins, Sons & Co., 5/-.

*1943 NICOL, Hugh. *Biological control of insects.* Harmondsworth: Penguin Books Ltd.

1944 GARRETT, S. D. *Root disease fungi.* Waltham, Mass.: Chronica Botanica Co., $4.50.

1944 HALL, Sir A. D. *The feeding of crops and stock.* Parts 1 and 2 revised by Sir W. G. Ogg. 3rd edition. London: John Murray, 12/-.

1946 RUSSELL, Sir E. J. *British agricultural research: Rothamsted.* Revised edition. London: published for the British Council by Longmans, Green & Co., 1/6.—Available from the Librarian, Rothamsted Experimental Station, as also are a Spanish translation (new impression, 1947, 1/-) and a Portuguese translation (1942, 1/-).

1948 BUTLER, C. G. *The importance of bees in orchards.* Ministry of Agriculture Bulletin no. 328. London: H.M. Stationery Office, 9*d.*

1948 FISHER, Sir R. A. *Statistical methods for research workers.* 10th edition. Edinburgh: Oliver & Boyd, 16/-.

1948 GARNER, H. V. *& others. Profit from fertilizers.* 3rd edition. London: Crosby Lockwood & Son, Ltd., 15/-.

1948 RUSSELL, Sir E. J. *A student's book on soils and manures.* 4th edition. Cambridge University Press, 8/6.

1948 TRACEY, M. V. *Proteins and life.* London: Pilot Press; reprinted by Chapman & Hall Ltd., 10/6.

1948–56 BARNES, H. F. *Gall midges of economic importance.* Volumes 1–7. London: Crosby Lockwood & Son, Ltd. Vol. 1, 12/6; Vols. 2–6, 15/-; Vol. 7, 21/-.

1949 BUTLER, C. G. *Beehives.* Ministry of Agriculture Bulletin no. 144. London: H.M. Stationery Office, 9*d.*

1949 BUTLER, C. G. *The honeybee: an introduction to her sense-physiology and behaviour.* London: Oxford University Press, 10/6.

1949 HALL, Sir A. D. *The soil: an introduction to the scientific study of the growth of crops.* 5th edition. London: John Murray, 9/-.

1949 LONG, H. C. & BRENCHLEY, Winifred E. *The suppression of weeds by fertilizers and chemicals.* 3rd and enlarged edition. London: Crosby Lockwood & Co., 7/6.

* Out of Print.

1949 PIRIE, N. W. *The nature of the bacterial surface.* Edited by A. A. Miles & N. W. Pirie. Oxford: Blackwell Scientific Publications, 15/-.

1950 BAWDEN, F. C. *Plant diseases.* Revised edition. London: Thomas Nelson & Sons Ltd., 8/6.

1950 BAWDEN, F. C. *Plant viruses and virus diseases.* 3rd edition. Waltham, Mass.: Chronica Botanica Co., $4.75.

1950 RUSSELL, Sir E. J. *Lessons on soil.* 2nd ed. Cambridge University Press, 7/6.

1950 RUSSELL, Sir E. J. *Soil conditions and plant growth.* 8th edition, recast and rewritten by E. Walter Russell. London: Longmans, Green & Co., 35/-.

*1951 GOODEY, T. *Soil and freshwater nematodes.* London: Methuen & Co., Ltd., 45/-.

1951 FRANKLIN, Mary T. *The cyst-forming species of Heterodera.* Farnham Royal: Commonwealth Agricultural Bureaux, 18/6.

1951 PIRIE, N. W. *Four thousand million mouths.* Edited by F. Le Gros Clark & N. W. Pirie. Oxford University Press, 12/6.

1953 BOALCH, D. H. *The manor of Rothamsted.* Harpenden: Rothamsted Experimental Station, 7/6.

1953 FISHER, Sir R. A. & YATES, F. *Statistical tables for biological, agricultural and medical research.* 4th edition. Edinburgh: Oliver & Boyd, 21/-.

1953 RIBBANDS, C. R. *The behaviour and social life of honeybees.* London: Bee Research Association Ltd., 21/-.

1954 BOALCH, D. H., *ed. Catalogue of serial publications in the library of Rothamsted Experimental Station, 1953.* Harpenden: Rothamsted Experimental Station, 17/6.

1954 BUTLER, C. G. *The world of the honeybee.* (New Naturalist series.) London: Collins, 21/-.

1954 GOLDSCHMIDT, V. M. *Geochemistry.* Edited by A. Muir. Oxford: Clarendon Press, 63/-.

1954 RUSSELL, Sir E. J. *World population and world food supplies.* London: Allen & Unwin Ltd., 50/-.

1954 TRACEY, M. V. *Principles of biochemistry: A biological approach.* London: Sir Isaac Pitman & Sons, Ltd., 20/-.

1955 HALL, Sir A. D. *Fertilizers and manures.* 5th edition. London: John Murray, 10/6.

1955 PENMAN, H. L. *Humidity.* London: Institute of Physics, 5/-.

1955–56 TRACEY, M. V. *Modern methods of plant analysis.* Edited by K. Paech & M. V. Tracey. Berlin: Springer-Verlag, 4 Volumes, £43 16*s.* 6*d.*

1956 RUSSELL, Sir E. J. *The land called me.* London: Allen & Unwin, 25/-.

1957 BROADBENT, L. *Investigation of virus diseases of brassica crops.* (A.R.C. report series, no. 14.) Cambridge: University Press, 15/-.

* Out of Print.

1957 BUTLER, C. G. *Beekeeping.* Bulletin Min. Agric. Fish. & Food, 9. [9th edition.] London: H.M. Stationery Office, 2/-.

1957 GARNER, H. V. *Manures and fertilizers.* Bull. Min. Agric. Fish & Food no. 36. [11th edition.] London: H.M. Stationery Office, 4/6.

1957 GARNER, H. V. *The use of lime in British agriculture.* By H. W. Gardner & H. V. Garner. 1st popular edition. London: E. & F. N. Spon Ltd., 15/-. [First edition, 1953.]

1957 GOODEY, J. B. *Laboratory methods for work with plant and soil nematodes.* Ministry of Agriculture Technical Bulletin no. 2. [3rd edition.] London: H.M. Stationery Office, 3/6.

1957 GOODEY, T., GOODEY, J. B. & FRANKLIN, M. T. *The nematode parasites of plants catalogued under their hosts.* [2nd edition.] Farnham Royal: Commonwealth Agricultural Bureaux, 27/6.

1957 RUSSELL, Sir E. J. *The world of the soil.* (New Naturalist Series.) London: Collins, 25/-.

1958 BOALCH, D. H. *Prints and paintings of British farm livestock 1780–1910: a record of the Rothamsted Collection.* Harpenden: Rothamsted Experimental Station, 21/-.

1958 BRENCHLEY, Winifred E. *The Park Grass plots at Rothamsted.* Revised by Katherine Warington. [Originally published 1924 as *Manuring of grassland for hay.*] Harpenden: Rothamsted Experimental Station, £1.

1958 JONES, F. G. W. *Sugar beet pests.* Bull. Min. Agric. Fish & Food no. 162. London: H.M. Stationery Office, 6/6.

1958 MELLANBY, K. *The birth of Nigeria's university.* London: Methuen, 25/-.

1958 WILLIAMS, C. B. *Insect migration.* (New Naturalist Series) London: Collins, 30/-.

1959 FRANKLIN, M. T. & HOOPER, D. J. *Plants recorded as resistant to root-knot nematodes* (Meloidogyne *spp.*). Farnham Royal: Commonwealth Agricultural Bureaux, 7/6.

1959 FREE, J. B. & BUTLER, C. G. *Bumblebees.* (New Naturalist Series.) London: Collins, 25/-.

1959 GOODEY, J. B., FRANKLIN, M. T. & HOOPER, D. J. *Supplement to the nematode parasites of plants catalogued under their hosts, 1955–58.* Farnham Royal: Commonwealth Agricultural Bureaux, 7/6.

1960 BOALCH, D. H. *World directory of agricultural libraries and documentation centres.* Harpenden: International Association of Agricultural Librarians & Documentalists, 35/-.

1960 COOKE, G. W. *Fertilizers and profitable farming.* London: Crosby Lockwood, 15/-.

1960 HULL, R. *Sugar beet diseases.* Bull. Min. Agric. Fish & Food no. 142. London: H.M. Stationery Office.

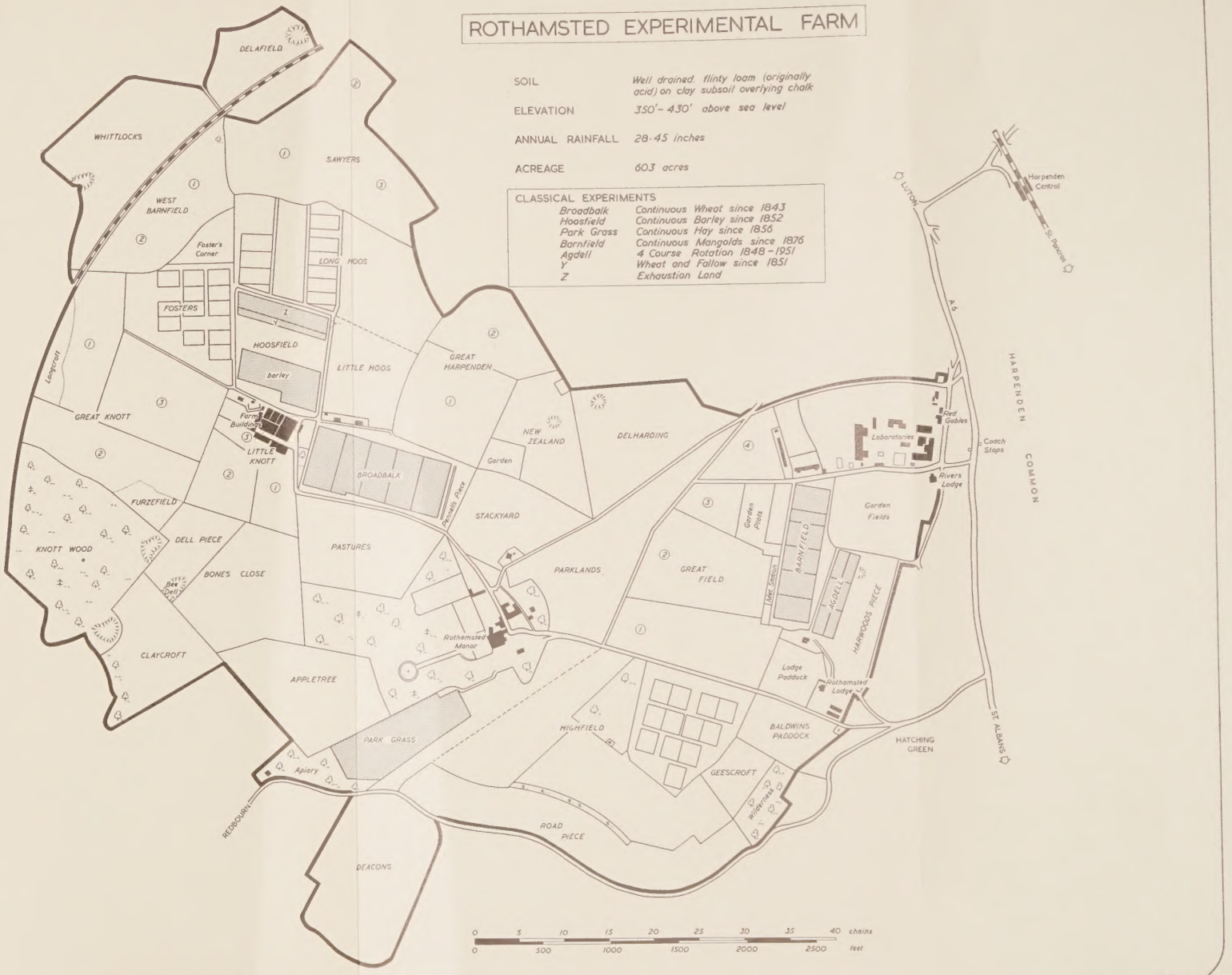
1960 YATES, F. *Sampling methods for censuses and surveys.* 3rd edition. London: Griffin.

1961 BROWN, G. *The X-ray identification and crystal structures of clay minerals.* Edited by G. Brown. [2nd edition.] London: Mineralogical Society, 84/-.

1961 GREGORY, P. H. *The microbiology of the atmosphere.* London: Leonard Hill, 60/-.

1962 SHEPHERD, A. M. *The emergence of larvae from cysts in the genus Heterodera.* Farnham Royal: Commonwealth Agricultural Bureaux, 20/-.

Printed in Great Britain by
Richard Clay and Company, Ltd.
Bungay, Suffolk.


ROTHAMSTED EXPERIMENTAL FARM
SOIL
Well drained, flinty loam (originally acid) on clay subsoil overlying chalk
ELEVATION
350'– 430' above sea level
ANNUAL RAINFALL
28·45 inches
ACREAGE
603 acres
CLASSICAL EXPERIMENTS
Broadbalk Continuous Wheat since 1843
Hoosfield Continuous Barley since 1852
Park Grass Continuous Hay since 1856
Barnfield Continuous Mangolds since 1876
Agdell 4 Course Rotation 1848 – 1951
Y Wheat and Fallow since 1851
Z Exhaustion Land
DELAFIELD
WHITTLOCKS
WEST BARNFIELD
SAWYERS
Foster's Corner
LONG HOOS
FOSTERS
HOOSFIELD
barley
LITTLE HOOS
GREAT HARPENDEN
Longcroft
GREAT KNOTT
Farm Buildings
LITTLE KNOTT
NEW ZEALAND
DELHARDING
Garden
BROADBALK
Pinetells Piece
STACKYARD
FURZEFIELD
DELL PIECE
KNOTT WOOD
BONES CLOSE
Bee Dell
PASTURES
PARKLANDS
GREAT FIELD
Garden Plots
BARNFIELD
Mart Station
AGDELL
HARWOODS PIECE
Garden Fields
Laboratories
Red Gables
Coach Stops
Rivers Lodge
Rothamsted Manor
CLAYCROFT
APPLETREE
Lodge Paddock
Rothamsted Lodge
HIGHFIELD
BALDWINS PADDOCK
PARK GRASS
Apiary
GEESCROFT
Wilderness
ROAD PIECE
DEACONS
REDBOURN
HATCHING GREEN
LUTON
A6
HARPENDEN COMMON
ST ALBANS
Harpenden Central
St. Patricia
0 5 10 15 20 25 30 35 40 chains
0 500 1000 1500 2000 2500 feet
1958